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Engineering and Construction Division

PLANNING REPORT ON

THE PROPOSED RIO BLANCO EXTENSION

January, 1946

PUERTO RICO WATER RESOURCES AUTHORITY
Engineering and Construction Division

San Juan, Puerto Rico

January 8, 1946.

Mr. Antonio Lucchetti
Executive Director
P. R. Water Resources Authority
SAN JUAN, Puerto Rico

Dear Mr. Lucchetti:

There is submitted herewith a report on the proposed RIO BLANCO EXTENSION. This project will provide a high utilization of the heavy run-off of the upper El Yunque area by the construction of a dam on the Hicaco river; thereby affording seasonal storage not only for the proposed generating plant but also for the existing Rio Blanco plant.

The reservoir will be located within the limits of the Caribbean National Forest Reserve, and in addition to its use for power generation, a considerable recreational value will be afforded to this area. Since the U. S. Federal Forest Service at one time contemplated the construction of a reservoir for the purpose of recreation only in approximately the same site at a cost of more than $500,000, it is possible that some financial assistance may be obtained from either the Federal Government or the Insular Park Service in the construction of this dual-purpose reservoir.

Our six-year plan contemplates starting the construction of this project in the next fiscal year (1946-47), and our budget for this period should provide a sum equivalent to 75% of the estimated project cost, or $1,725,000.

Very truly yours,

CA Bock
Carl A. Bock
Chief Engineer

RIO BLANCO EXTENSION PROJECT

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INTRODUCTION

The Porto Rico Railway Light and Power Company completed construction of the Río Blanco Hydro-Electric Development in 1930. The project is located within the limits of the Caribbean National Forest Reserve in the eastern part of the Island on the southeastern slope of the Luquillo Mountain Range about 60 kilometers southeast from San Juan and 15 kilometers northwest of Naguabo. It consists of a run-of-river generation plant operating under a head of 1300 feet and fed by a system of canal waterways, which collect a portion of the unregulated run-off of 6.7 square miles of watershed. (Exhibit No. 4 Appendix "B" shows the general layout of the project in schematic form).

This project, together with other properties of the Porto Rico Railway Light and Power Company, was acquired by the Puerto Rico Water Resources Authority in 1943. Immediately thereafter, studies were initiated by the Authority to investigate the economic feasibility of providing storage for this project in order to increase the plant utilization factor and thereby obtain a higher prime energy output.

On the outset it was obvious that such storage must necessarily be located on the Hicaco River, the largest tributary of Río Blanco. Studies and field investigations for a dam site were, therefore, directed along the upper reach of this river.

SUMMARY

Office studies, combined with a thorough field investigation of the dam site, have led to the conclusion that stream regulation provided by seasonal storage is feasible and economically justified.

The plan proposed herein, and referred to hereinafter as the Río Blanco Extension, consists of the construction of a storage dam (referred to hereinafter as Hicaco Dam) on the Hicaco River about one mile upstream from the existing small diversion dam of the Río Blanco waterway; a system of conduit diversions to collect the flow from the Río Blanco tributaries at a higher elevation than the existing diversions and discharge them into the proposed reservoir; and a power plant to be operated under an average net head of 580 feet and discharging its tailwater into the waterway of the existing lower development. (See Drawing No. 1 for a general plan of the project.)

The run-off from 3.6 of the 6.7 square miles of drainage area of the existing Río Blanco Project will be brought under almost complete regulation, and it will be utilized through heads of both the new and existing power plants.

The proposed dam would be of concrete gravity type with a crest length of 390 feet, and it would be 90 feet high at the maximum section. The diversion waterway would consist of 18,350 lineal feet of precast-concrete pipe constructed on a grade contour, and 3,100 lineal feet of small bore tunnel. The conduit from the dam to the proposed power plant would consist of 5,500 lineal feet of concrete pipe under pressure and 1,600 lineal feet of steel penstock. The proposed power plant would have an installed capacity of 2,300 kilowatts, which under a net operating head of 580 feet and with average annual flow of 26.0 cfs

will generate approximately 9,000,000 kilowatt-hours of energy annually, and it is estimated that the proposed development will increase the annual output of the existing Rio Blanco project by 13,197,000 kilowatt hours without additional cost to the plant. The total annual energy to be credited to the extension project is thus estimated at 22,197,000 kilowatt hours, which more than doubles the present generating capacity of Rio Blanco development. Approximately 90 percent of this increased production will be prime power. The estimated cost of the project is $2,300,000, and the cost per kilowatt-hour of energy will be about 5 1/2 mills. The ratio of the annual benefit to cost is estimated to be 1.4.

The project will have considerable recreational value, as the lake formed by the dam will lie adjacent the existing Luquillo Park recreation facilities in the National Forest. Application for Federal and/or Insular aid should therefore be made for obtaining assistance in financing the project.

Further planning studies are being made toward the possibility of enlarging the project by diverting to the reservoir additional run-off from headwater areas to the north. A report on this study will be presented at a later date.

This report has been prepared by R. C. Price, assisted by Mr. R. Nevares, Jr.; Messrs. Aguilar and Sólivan were responsible for the compilation of the hydrographic data.

BASIN DESCRIPTION

General

The Río Blanco Basin, comprising an area of 28 square miles, is located in thé southern section of the Luquillo Mountain Range, and it includes some of the highest peaks, (maximum elevation 3400 ft. msl) to be found along the Insular Divide. The topography of the basin may roughly be divided into three principal divisions; coastal plain, marginal lands, and mountain terrain. The percentage area of each division are approximately 30, 10, and 60 per cent respectively. The headwaters area of the basin, or mountainous section, is extremely rugged with definite topographic trends of ridges, peaks, etc., while the marginal lands are rough, fairly steep, but the relief is less and the topography is irregular. The coastal plain is flat and at the average elevation of 65 feet, msl.

Geology

The geology is, apparently, rather complex. Mr. Howard A. Meyerhoff* has classified the rock structure as follows:

<u>In the Headwater and Marginal Areas:</u> "Upper cretaceous pyroclastic formations, including massive andesitic tuffs and agglomerate, and associated conglomerates. South of this formation may be found a zone, (location of dam site) of granitoid intrusives including diorites, quartz diorite, granites and other holocrystalline types. Further south and extending into the marginal lands may be found intrusive porphyries, chiefly andesitic, invading the Upper Cretaceous sedimentary and pyroclastic rocks."

<u>In the Coastal Plain:</u> "Recent unconsolidated littoral, alluvial, and eolian deposits; consolidated dune sands and littoral sediments of Pleinstocene age."

The soils in the proposed project area are decidedly residual, and being derived from a coarse-grained, crystalline rock they show

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* Geology of Puerto Rico - 1933

a granular structure. In fact, the soils near the rock stratum are almost pure sand, as shown by the wash from the drill borings at the dam site."

River System

The Hicaco River is the principal tributary forming the Río Blanco. Its source is located well upon the southern slopes of the peak El Yunque and it flows almost due south until a confluence is made with Peña Pobre River; thence its direction (now as Río Blanco) turns southeast and flows into the sea at about the junction point of the Atlantic Ocean and Caribbean Sea.

The stream profile is fairly flat in the extreme headwaters area, but the drop from the southern rim of the mountains to the coastal plain is exceptionally steep, about 1,800 feet in 2.5 miles. (See River Profile Drawing No. 2).

The river channel is flanked with steep slopes throughout the mountain area of the watershed, but the soil and subsoil (identified by the U. S. Department of Agriculture as Los Guineos clay) in general are fairly deep and covered by dense tropical vegetation.

The river system (Hicaco-Blanco) from the source to the sea is about 12.5 miles long.

While flood run-off is rapid in the mountain areas the surface cover and soil appear to have considerable storage effect even in small areas. This natural storage apparently is augmented by the influence of small strips of clay soil occurring in all parts of the area in more or less flat or horizontal positions, which retain a high per cent of moisture and drain slowly.

The tributaries of the Hicaco River are the Sabana an Cubuy streams to the west and Río Prieto to the east. Tributaries of the

Río Blanco are the Peña Pobre from the southwest and the Maizales from the north. The main stem and the tributaries are used for the development of hydroelectric power, irrigation of the coastal-plain lands, and water supply.

Hydrology

The mountain area of the basin is located directly in the path of the northeastern moisture laden trade winds which, when deflected upward by the high terrain to the north, drop an abundant rainfall over tho region resulting in the highest average annual precipitation recorded in the Island. Gaging of the rainfall along the northern fringe of the basin shows an average (9-year record) of 185 inches. (See Table No. 4, Appendix "B") The average annual precipitation in the project area is estimated at 154 inches, which is spread more uniformly than any other section of the Island. (Graph No. 2, Appendix "B" shows the "Variation of Relative Intensity of Rainfall at Different Sections of the Island"). Clouds and fog are common, even in the dry season from December to April, inclusive.

Good stream flow records are lacking. Daily records of flows through the Río Blanco Hydroelectric Plant are available for the period 1930-1944, inclusive. A detailed study of comparison between rainfall and run-off in adjacent similar basins has revealed that the expected run-off in the mountain area is at least 40 acre-feet per square mile per inch of rainfall (See Table No. 1, Appendix "B").

An automatic recording gage was installed at the proposed dam site on the Hicaco River on July 5, 1945. Accurate and dependable run-off records for this drainage area are now being compiled. (See Graph

No. 1, Appendix "B").

The yearly temperature range is between about 50 to 85°F in the mountain section. The nights are always cool the year around. Evaporation and transpiration losses amount to approximately 39 inches yearly in the headwaters area.

Floods occur often during the wet season from May to November, inclusive, but those of major magnitude have an approximate 8-year frequency; occurring in association with tropical hurricanes.

Electric Power Facilities

In the basin there are located one power generating station; the Río Blanco plant, to which the proposed project herein described affords much benefit. The plant equipment consists of two H. M. Goith Heindenhein (German manufactured) impulse turbines, 3500 H.P., 720 RPM, and equipped with 20 buckets each; and two Westinghouse, 3125 KVA, 4400 volts generators in direct connection to the turbines.

A Federal owned steam-electric station is located at the Roosevelt Naval base near Ceiba, about 10 miles east of the Río Blanco plant. It is interconnected to the Authority's system and can deliver (by contract) up to 8000 KW to the Insular transmission system.

The electrical transmission facilities in the basin include the 38 KV loop, Fajardo-Río Blanco tying to the Río Blanco-Río Piedras line. This loop will serve temporarily until the new line-construction program is completed, and will be used to supply power for the construction of the Hicaco project.

HISTORICAL DATA

Prior Studies and Reports

The Porto Rico Railway Light and Power Company at one time contemplated the construction of a storage reservoir at the approximate site selected by the Authority. In 1928 the company made preliminary surveys of the reservoir and developed area-capacity curves.

In 1938 the U. S. Forest Service proposed to create a lake for recreational purposes by building a dam immediately upstream from the site proposed in this report. Extensive sub-surface explorations were performed at the dam site by means of hand-auger borings, test pits, and core borings. The auger holes were limited in depth by the equipment to about 22 feet. Twenty four shot-core borings were made with penetration into solid rock varying from 12 to 36 feet.

This project was studied and a report prepared by the Utilization of the Water Resources Division for the Forest Service. The report is dated August 7, 1939, and is titled "Hicaco Dam - Comparative Designs and Costs".

Plans of the U. S. Forest Service: As a result of the aforementioned study, a concrete gravity dam was recommended as the best suited structure for the site.

It was proposed to build the structure 92 feet high at the maximum section, and 330 feet long at the crest. The core walls at either end of the dam would extend 100 feet into the abutment. The spillway would have been an overflow type 99 feet long and comprising the middle section of the dam.

STUDIES BY THE AUTHORITY

Field Investigations

In November 1944 the Puerto Rico Water Resources Authority began a field investigation of the proposed project. This work consisted of engineering surveys and foundation explorations. The first site to be investigated is located about 0.6 kilometers downstream from the location finally selected. Studies based on these surveys and foundation explorations including 8 test drill holes, revealed that a dam located here could not be economically justified, and in May 1945 the site was abandoned. The equipment and survey crews were moved upstream to the area of the site investigated by the U. S. Forest Service to explore further the possibility of a storage reservoir. Preliminary surveys of the dam site, reservoir, and diversion waterways together with drilling of nine borings and sinking one test pit on the dam site foundation, were completed between May 15 to July 15, 1945. (See "Foundation Investigation Reports" contained in the Appendix "A").

Determination of the Power Available

In analyzing the power benefits of the proposed project and the increased output of the existing Río Blanco Development, it has been necessary to use rainfall records as a base for run-off quantities. It is recognized that this method of stream flow evaluation is inadequate and may lead to serious error in estimating the energy available. For this reason the results obtained were checked by calculating the utilization factor of the existing Río Blanco plant from a 15-year record of the spillings. The waste of water plus that utilized by the plant checked the run-off as calculated by rainfall records very

closely. (See Table No. 2, Appendix "B") Therefore, it is believed the results shown herein are satisfactory, although little is known of the stream flow pattern at the dam site.

Usable Flow: Daily records of flow through the Rio Blanco plant are available for the period from 1935 to 1944, inclusive. These records are useful in determining the minimum flows, but are of little value in calculating the average annual run-off, owing to the lack of storage.

In order to estimate the average expected flows from rainfall records, it was necessary to correlate the known rainfall and run-off records of other similar areas to determine the run-off coefficient of the Hicaco watershed.

The conditioning factors of altitude, temperature, vegetation, soils, topography, and size of drainage areas are sufficiently similar between these recorded streams and those of the Luquillo Mountain Range as to warrant, with reasonable accuracy, the use of similar average run-off factors.

Table I, (Appendix "B") shows the result of this comparison study, indicating that an average annual run-off of at least 40 acre-feet per square mile per inch of rainfall may be expected from mountain areas of this nature. On this basis, it is estimated that a total average annual run-off of 40 x 154 x 6.705 = 41,300 acre feet is available over the watershed of the proposed and existing projects; representing an average net run-off of 115 inches and leaving (154-115) 39 inches as evaporation and transpiration losses.

A compilation of flows at the plant and the existing diversion

dam show that the run-off is more evenly distributed in this area than any other yet studied. In other words, considerable precipitation occurs even in the dry season. This condition is better illustrated by the fact that Río Blanco is now utilizing about 50% of the total run-off, even with no storage and only 9 acre-feet of pondage.

In calculating the usable flow, the following run-off utilization factors were used:

1. At the dam site with 1.26 square miles of drainage area the utilization is estimated at 95 per cent.

2. The tunnel diverting water from Sabana Creek to the reservoir would have a capacity about 15 times the average annual flow from the 0.90 square miles of drainage area. The utilization is, therefore, estimated at 85 per cent.

3. The capacity of the conduits for diverting the water from the remaining 1.43 square miles would be about three times the average annual flow. The utilization is, therefore, estimated at 70 per cent.

4. The present utilization of the total area (6.71 square miles) through the Río Blanco plant is about 50 per cent. With the 3.60 square miles of the upper section of the watershed being diverted to the reservoir, the the utilization factor for the remaining 3.11 square miles has been estimated at 75 per cent.

With an average recorded rainfall of 160 inches (less 39 for evaporation and transpiration losses), and a run-off factor as shown above, the average annual yield for each drainage area of the upper system is as follows:

1. Dam site,
   (1.264 x 640 x 121/12 x 0.95) ...... 7,750 Ac.Ft.

2. Sabana Creek,
   (0.90 x 640 x 121/12 x 0.85) ...... 4,950 Ac.Ft.

3. Other Diversions,
   (1.427 x 640 x 121/12 x 0.70) ..... 6,450 Ac.Ft.

   Total usable yield at upper plant .... 19,150 Ac.Ft.

The yield of the lower system on 3.11 square miles with 148 inches of rainfall (less 40 inches for losses) at a run-off factor of 75 per cent is,

3.114 x 640 x 108/12 x 0.75 .... 13,450 Ac. Ft.

The total expected annual yield for the lower plant is, therefore, 32,600 acre-feet.

Regulation Obtained: The reservoir created by the proposed dam with the maximum power pool at elevation 2084 will provide 3200 acre-feet of usable seasonal storage. This reservoir capacity is assumed to be used principally for regulating the flow through the Rio Blanco plant. Studies made from the mass diagram of flows at the dam site reveal that the capacity of the reservoir is adequate for 95 per cent stream regulation in the average year. Furthermore, these studies indicate that additional storage up to 100 per cent flow regulation is not economically justified.

The study showing the regulation afforded by the Hicaco reservoir is shown graphically in Exhibit No. 2, Appendix "B". As shown, the regulation afforded will provide a flow at the lower plant, of between 40 and 45 cfs during most of the time. The plant capacity factor will be raised from 50 to 75 per cent owing to this higher utilization factor, which is made possible be seasonal storage.

It will be seen that the continuous flow in the most critical period on record will be 20 cfs at the upper plant and 25 cfs at the lower plant. This is an increase of about 15 cfs at each plant over the unregulated flow.

Firm Power - Critical Period: The hydrographic studies reveal that the most critical period on record (1921 to 1924, inclusive) occurred in 1936, when the average monthly flow for March was less

than 10 second feet. With the addition of the Hicaco project, this critical period flow will be augmented by the storage provided and the resulting critical period dependable power will be 840 KW for the upper plant, and 2800 KW for the lower plant; representing an annual production of 7,350,000 KWH and 24,500,000 KWH of prime power, respectively. This is an increase of 1975 KW of dependable capacity, and about 17,300,000 KWH of annual prime energy to be credited to the Rio Blanco Extension project.

Energy Production: The average head losses due to drawdown in the reservoir and to friction in the conuit and penstock is calculated at 30 feet, giving an average net head in the upper plant of 580 feet. Under this head the usable flow of 19,150 acre-feet will yield an average annual energy output of 9,000,000 KWH. The existing lower plant, with an average net operating head of 1300 feet, will produce 34,757,000 KWH on a usable flow of 32,600 acre-feet. The average annual energy at the two plants combined will be 43,600,000 KWH. The present output of the existing Rio Blanco plant is estimated at 21,560,000 KWH; making a total annual energy output creditable to the proposed Hicaco project of 22,197,000 KWH. The proposed usable storage of 3200 acre-feet represents about 5,000,000 KWH of stored energy.

Project Layout and Design Considerations

Under this heading the principal features of the project will be described in some detail, and reasons given for the selection of the particular type of structure. The development of final project designs in detail is outside the scope of this report, and the preliminary layout designs shown in the appendix are the result of the pre-

liminary planning, and are used as a basis for estimating the construction cost.

The Dam: In 1938 the writer made extensive laboratory tests on the soils as well as some design studies for the U. S. Forest Service for a dam at this site. As a result of this work, it became quite obvious that a concrete structure should be recommended. An earth dam structure was found to have the following disadvantages:

(a) Unsuitability of the soils for embankment construction,

(b) Unsuitability of the earth overburden to support an embankment,

(c) Unsuitable weather for earth embankment construction, and

(d) Expensive spillway construction.

The studies indicated that a rock fill type would not be suitable because:

(a) Unsuitability of the soil to support a rock embankment, and

(b) Expensive spillway construction.

A concrete gravity type of dam is largely free from these disadvantages and was found to afford a more economical construction. The dam, as proposed herein, would be located about 50 feet downstream from the site selected by the Forest Service. Its final location was determined from a rock contour plan, which was developed from results of the sub-strata explorations.

The earth overburden, ranging in depth from 10 to 60 feet, is residual in nature and granitoid in texture. It has a high coefficient of internal friction and may be expected to stand on steeply excavated slopes. Concentric-weathered boulders, some up to 20 feet

in diameter, may be expected to be uncovered in the excavation.

The underlying rock is classified as a quartz-diorite. It is hard, massive and with little indication of fractures and joint planes. In the drilling operations there was practically no loss of core after bed rock was reached. There is almost no zone of rotten or desintegrated rock between the soil and sound bed-rock, as is usually found when similar foundations are uncovered. It is expected that very little grout will be necessary for the cut-off curtain and general foundation consolidation.

Drawing No. 5 shows a plan and elevation of the proposed structure and Drawings Nos. 3 and 4 show the expected foundation conditions. The gravity dam will be 390 feet long, including spillway, at the crest and 90 feet high at the maximum section. The elevations, based on mean sea level datum, will be:

Lowest point of foundation	2000 feet
Spillway crest	2084 feet
Non-overflow crest	2094 feet

The spillway section will be 100 feet long and is designed to pass a peak flood of 5500 cfs, which with the large surcharge storage available on the small drainage area, is equivalent to a design flood of 12,000 second-feet. A heavily reinforced corewall will project from either end of the dam into the hillside about 40 feet. A well compacted earth fill will overlap these corewalls and a portion of the gravity section of the dam to serve as a cutoff around the ends of the structure. Heavy rock-fill blankets will be placed on the earth abutments downstream of the dam to provide stability against

sliding of the earth slopes.

Stream diversion during construction would be confined to its regular channel by a cofferdam during the building of the south section of the dam, and then diverted through the previously prepared sluiceway in this section while constructing the north portion.

The Reservoir: The reservoir will cover an area of 170 acres, and extend upstream from the dam a distance of 5300 feet. The total volume to the maximum flood pool elevation (2090) will be 4180 acre-feet, and proportioned as follows:

Dead Storage	200	Acre-feet.	
Usable Storage	3200	"	"
Surcharge Storage	780	"	"

The elevations of the reservoir to provide this capacity will be:

Dead storage from	Elev. 2020 to Elev. 2036 msl
Usable storage from	Elev. 2036 to Elev. 2084 msl
Surcharge storage "	Elev. 2084 to Elev. 2090 msl

Owing to the heavy tropical vegetation covering almost the entire watershed which will prevent erosion, it is believed that silting of the reservoir will be almost negligible.

The Diversion Waterways: The General Plan and Profile, Drawing No. 1, shows the principal features of the proposed diversion system. This system will divide the drainage area (6.7 square miles) of the existing Río Blanco Project into two sections; placing 3.6 square miles of the watershed into the upper system, regulating the runoff in the Hicaco reservoir, and leaving 3.1 square miles of drainage area as unregulated runoff for the existing Río Blanco plant.

The proposed diversion system will require the construction of eight small diversion dams, 18,350 lineal feet of precast-concrete pipe, and 3,000 lineal feet of tunnel. The concrete pipe will divert the water by gravity flow on a grade contour. The pipe sizes required will be 9,350 lineal feet of 24-inch diameter, 8,200 lineal feet of 30-inch diameter, and 800 lineal feet of 60-inch diameter. The tunnel will be a 4-foot x 6-foot section, and it is believed that lining will not be necessary.

The flow will be carried from the reservoir to the new power plant through a waterway consisting of a 48-inch diameter precast-concrete pressure pipe approximately 5,500 feet long, and connected at the lower end to a 36-inch welded steel-pipe penstock about 1,600 feet long. The conduit intake will be located on the right abutment of the dam some 47 feet below the spillway level.

The Power Plant: The power plant will be located on the right bank of the Hicaco River with its tailwater discharging into the pool of the existing Hicaco Diversion Dam. The installed capacity will be 2300 kilowatts, which will generate energy under an average net head of 580 feet. The equipment will include a horizontal double overhung impulse wheel developing 3000 H.P. and directly connected to a 2500 KVA capacity generator.

The proposed new plant will be automatically operated by remote supervisory control from the existing Río Blanco Plant. The operation of the two plants will be integrated, with the upper plant working as a flow regulator for the lower plant. The maximum flow capacity at the upper plant will be 55 second-feet.

Construction Features

Access: A paved highway, the Río Blanco-Mameyes Road, passes along the right abutment of the dam about 20 feet above the crest elevation of the proposed dam. It also extends around the south side of the reservoir just above the proposed maximum pool level.

The American Railroad affords rail connection up to about 1 Km. from Río Blanco plant or about 5 miles by road of the proposed dam.

The power plant is located about 1/4 mile from the above mentioned Insular Road, and an access road about 1.5 miles long will have to be provided as a spur to the plant.

Much of the waterway location is inaccessible, and access trails will be required for construction.

Camp and Plant Site: An excellent location is available along the road and nearby the dam site for such camp and plant facilities as will be required. This is the site of an old CCC camp.

Construction Equipment: The site of the proposed dam appears to be well suited for the use of hydraulic sluicing equipment (Pumps and hydraulic giants) for the excavation job. However, if this type of equipment is used the sluicing should be done during the wet season in order to be assured of a sufficient amount of water.

Other equipment suitable for concrete placing and rock fill work would include derricks or a small cableway. Also, pumpcrete equipment could be used economically for placing the concrete. There is sufficient flat space for the concrete plant.

Construction Materials: Sand and gravel deposits are found at the foot of the mountain on the Río Blanco. The haul to the dam site

will be about 4 miles, but undoubtedly this is the best source of concrete aggregates. The large size aggregates can be produced by quarrying and crushing the rock near to the dam. There are many outcrops of good quality rock in the immediate vicinity.

Power for Construction: It will be necessary to construct about 2-1/4 miles of 38 KV power line from the Rio Blanco switchyard to the dam site for construction purposes.

Construction Program: It is estimated that the construction period will be 18 months. If the sluicing of the foundation excavation were started in October, there would be two dry seasons available for construction work.

Recreational Feature

The Hicaco Reservoir will be located in an area that has already been developed as a forest park for recreation with cottages, trails, swimming pool, and other facilities. The addition of the Hicaco lake to these existing recreational features will greatly enhance the usefulness of the area, and add an important item of scenic beauty.

Estimate of Cost

The estimate of cost, shown on the following pages, is based on the foundation conditions and type of structures as shown on Drawings Nos. 3 to 5 inclusive. The cost of transmission lines has not been included. The unit costs are based on the approximate ENR index for 1944 which, of course, takes into account the inflation of war time conditions.

RIO BLANCO EXTENSION PROJECT

PRELIMINARY COST ESTIMATE

FEATURE	UNIT	QUANTI-TY	UNIT COST	AMOUNT	ESTIMATED COST
PRELIMINARY					
Engineering Surveys	L. S.	-- --	-- --	15,000	
Foundation Explorations	L. S.	-- --	-- --	10,000	$ 25,000
GENERAL CHARGES					
Construction Buildings	L. S.	-- --	-- --	15,000	
Permanent Operators Quarters	L. S.	-- --	-- --	3,000	
Access Roads	Mile	1.5	$20,000	30,000	$ 48,000
LANDS ACQUISITION & CLEARING					
Lands Purchased	Acre	160	60.00	9,000	
Clearing of Land	"	150	50.00	8,000	$ 17,000
DAM & APPURTENANCES					
Stream Diversion	L. S.	-- --	-- --	40,000	
Excavation - Earth	Cu.Yd.	100,000	0.80	80,000	
Excavation - Rock	" "	5,000	3.00	15,000	
Backfill - Earth	" "	20,000	1.00	20,000	
Rip-rap - Rock	" "	70,000	2.00	140,000	
Concrete - Mass	" "	35,000	11.00	385,000	
Concrete - Reinforced	" "	1,000	20.00	20,000	
Intake Structure	L. S.	-- --	-- --	35,000	
Grouting & Drainage	L. S.	-- --	-- --	10,000	$ 745,000
DIVERSION WATERWAYS					
Precast Concrete Pipe -24 in.	Ln.Ft.	10,000	10.00	100,000	
" " " 30 "	" "	8,000	12.00	96,000	
" " " 60 "	" "	800	25.00	20,000	
Tunnel - 4' x 6'	" "	3,100	40.00	124,000	
Diversion Dams	" "	8	10,000	80,000	$ 420,000
PRESSURE PIPE & PENSTOCK					
Precast Concrete Pipe 48 in.	Ln.Ft.	5,500	20.00	110,000	
Welded Steel Pipe 36 "	Ton	120	400.00	48,000	$ 158,000

RIO BLANCO EXTENSION PROJECT

PRELIMINARY COST ESTIMATE (Cont'd)

FEATURE	UNIT	QUANTITY	UNIT COST	AMOUNT	ESTIMATED COST
POWER PLANT & FACILITIES					
Substructure	Kw.	2300	19.60	45,000	
Superstructure	"	"	13.00	30,000	
Hydraulic Equipment	"	"	15.60	36,000	
Electrical Equipment	"	"	23.50	54,000	
Mechanical Equipment	"	"	7.85	18,000	
Misc. Low Tension Equipment	"	"	3.90	9,000	
Switchyard	"	"	13.00	30,000	
Power House Crane	L. S.	- -	- -	5,000	
Automatic Supervisory Equip.	L. S.	- -	- -	20,000	$ 247,000

TOTAL DIRECT COST....... $1,660,000

First Cost

Direct cost plus General Overhead, Engineering & Superintendence, and Contingency.

General Overhead at 15% -	$ 249,000	
Engineering & Superintendence at 10% -	166,000	
Contingency at 10% -	166,000	$ 581,000

Total First Cost $2,241,000

Investment Cost

First cost plus interest during construction - 18 months at 3% Interest

Item	Interest During Constr.	Total Cost
1. Preliminary & Lands	$ 2,300	$ 92,300
2. Dam & Appurtenances	22,500	767,500
3. Waterways & Penstock	12,500	590,500
4. Power Plant	4,000	251,000
5. Overhead & Contingency	17,700	598,700

TOTAL INVESTMENT COST .... $ 2,300,000

Economic Analysis

In analyzing the economics of this project the method of evaluation proposed by Mr. Miguel A. Quiñones on a report dated October 19, 1944, will be used. Briefly, the method consists of reducing the output of any hydro project, whether run-of-river or with storage, to firm continuous output through the addition of sufficient steam standby reserve. The economic feasibility of the project is then appraised by comparing this cost of production with the equivalent cost of production in an alternate base load steam plant which will produce the same firm output as the project under consideration.

Production, Present System

From actual production records, shown in table No. 5, appendix "B", the following data are obtained:

Average monthly output during an average wet season	....	1,924,000 KWH
Average monthly output during an average dry season	....	1,618,700 KWH
Critical dry season output (March and April 1936)	....	714,300 KWH
Steam standby capacity required to prime up all energy to 1,924,000 KWH per month at 70% plant factor $= \frac{1,924,000 - 714,300}{30 \times 24 \times 0.7} =$		2,400 KW.
Total average annual production = 1,924,000 x 12	....	23,088,000 KWH
Average annual energy by hydro = (1,924,000 x 7) + (1,618,700 x 5)	......	21,561,500 KWH
Average annual energy by steam	....	1,526,500 KWH

Estimated Productions, Present System
Plüs Proposed Additions

From runoff records at Río Blanco Sta. Elevation 1800 (see table No. 3, Appendix "B") the average dry season rainfall has been estimated at about 33% of the total annual rainfall.

Assuming the average usable runoff to be in the same proportion as the rainfall, then:

The average inflow into the reservoir during the five months of dry season = 33% of 19,150 Ac. Ft. = 6,320 Ac. Ft.

Adding to this inflow the 3,200 Ac. Ft. provided by the storage gives an average regulated outflow from the reservoir during an average dry season of 9,520 Ac. Ft.

The average inflow into the reservoir during the seven months of wet season = 67% of 19,150 Ac. Ft. = 12,830 Ac. Ft.

Subtracting the 3,200 Ac. Ft. needed to fill the reservoir gives an average regulated outflow from the reservoir during an average wet season of 9,630 acre feet. This average flow will be used at the upper plant.

The yield of the lower system estimated at 13,450 Ac. Ft. would be divided as follows:

Average during dry season 33% of 13,450 = 4,440 Ac. Ft.

Average during wet season 67% of 13,450 = 9,010 Ac. Ft.

Therefore, the usable flow at the lower plant during an average dry season would be 9,520 Ac. Ft. ≠ 4,440 Ac. Ft. = 13,960 Ac. Ft.

The usable flow at the lower plant during an average wet season would be 9,630 Ac. Ft. ≠ 9,010 Ac. Ft. = 18,640 Ac. Ft.

Estimated average monthly output
during average wet season

Upper plant $= \frac{9630}{7} \times 470$	....	646,000 KWH
Lower plant $= \frac{18,640}{7} \times 1060$	....	2,830,000 KWH
Total	....	3,476,000 KWH

Estimated average monthly output
during average dry season

Upper plant $= \frac{9,520}{5} \times 470$	....	895,000 KWH
Lower plant $= \frac{13,960}{5} \times 1060$	....	2,960,000 KWH
Total	....	3,855,000 KWH

Critical dry season (March and April 1936)
(From Differential Mass Diagram)

Upper plant = 1200 x 470	....	564,000 KWH
Lower plant = 1500 x 1060	....	1,590,000 KWH
Total	....	2,154,000 KWH

Steam standby capacity needed at
70% plant factor to prime up all energy
to 3,855,000 KWH, per month =
$\frac{3,855,000 - 2,154,000}{30 \times 24 \times .7} =$ .... 33,370 KW

Average annual prime energy output
= 3,855,000 x 12 .... 46,260,000 KWH

Average annual energy by hydro
= (3,855,000 x 5) + (3,476,000 x 7) .... 43,757,000 KWH

Average annual energy by steam .... 2,503,000 KWH

<u>Creditable to Proposed Rio Blanco Extension</u>

Increase in prime energy output
= 46,260,000 - 23,088,000 .... 23,172,000 KWH

Standby steam capacity required
to prime up all energy =
3,370 KW - 2,400 KW = ... 970 KW

Average annual production by hydro
= 43,757,000 - 21,561,500 .... 22,195,500 KWH

Average annual production by steam
- 1,652,000 - 1,526,000 .... 977,000 KWH

Cost of Energy (Produced by the Río Blanco Extension)

Annual Charges:

1.	Value of capacity required to prime up the entire generation 970 KW at $20.00	$ 19,400
2.	Variable fuel and other costs 977,000 KWH at 4.5 mills	4,400
3.	Interest at 3% ∤ depreciation at 1.6% - $2,300,000 x .046	105,800
4.	Operation and Maintenance	10,000
'.	Total annual charges excluding taxes	$ 139,600

Cost of Energy (If produced by steam)

Annual Charges:

1.	Capacity value at 60% Plant Factor $\left(\frac{1,975 \text{ KW}}{0.6} + 970 \text{ KW}\right) \times \$20$	$ 85,300
2.	Variable fuel and other costs 23,172,000 KWH at 4.5 mills	104,300
	Total annual cost of same energy by steam ...	$ 189,600

Comparison of Proposed Hydro Project with Equivalent Steam Development

Difference in annual cost between steam and hydro generation, favoring hydro	50,000
Additional justified investment over estimate $\frac{50,000}{0.046}$	1,087,000
Allowable capital investment for the proposed Rio Blanco Extension	3,387,000

APPENDIX "A"

PUERTO RICO WATER RESOURCES AUTHORITY
Engineering and Construction Division

San Juan, P. R.

July 30, 1945.

To : Mr. Carl A. Bock
Chief Engineer

Thru : Mr. Robert C. Price
Head Engineer

From : Rafael Reyes

Re : Rio Blanco Extension Project
Hicaco Dam Site Core Drilling

Transmitted herewith is the report on the core drilling operations performed at the Hicaco River dam site, Km. 17.2 Mameyes-Rio Blanco Road.

Rafael Reyes
Associate Engineer

RR/jmg

encl.

PUERTO RICO WATER RESOURCES AUTHORITY
Engineering and Construction Division

Hicaco River Project

Surveys and Foundation
Explorations Section

Exploration Drilling Report

by

Rafael Reyes
Associate Engineer
in charge of Surveys and
Drilling

July 28 - 1945

San Juan, Puerto Rico

Core Drilling - Hicaco Dam Site; Km. 17.2
Mameyes - Rio Blanco Road

Carl A. Bock, Chief Engineer

Robert C. Price, Head Engineer.

SUMMARY

Two core drills .... Used at Hicaco Dam Site for drilling on Foundation Explorations.

Two diamond drills (1 1/8" core) operated: 744 hours. From May 2 to July 5, 1945.

Diamond drilling rate per gross hour was

Abutment holes .... 1.44 ft. per hour

Combined cost per foot of hole drilled was

Abutment holes .... $ 3.15

These costs include operation, maintenance, depreciation, all supplies and direct engineering supervision. They are final field costs and are correct within 5% margin.

Introductory - This report describes, in general, the foundation exploratory work done at the proposed Hicaco Dam Site. This site is located near the Mameyes- Rio Blanco Road approximately at Km. 17.2. Core drilling operations are described herein as well as the equipment and method of performance used in these investigations. The work covered the period from June 24 to July 5, 1945. Cost of operations are given herewith.

This report supplements the one submitted on July 30, 1945 on core drilling operations.

Equipment:

Drills: Two #40 Sprague and Henwood core drilling machines, driven by a gasoline engine. Each machine is capable of drilling 1 1/8-inch holes to a depth of 700 feet.

The drills were equipped with 2" galvanized iron pipe tripods.

The drilling machines had been used on foundation exploration work at the Dos Bocas and the Caonillàs dam sites for about 3 years, and at the Hicaco River dam site at Km. 17.9, Mameyes - Río Blanco road for 4 months before they were moved to this location.

Engines: One 4 cylinder 10 H.P. Hercules gasoline engine and one 3 1/2 H.P. gasoline engines were used to operate the core drills.

Pumps: One Myers chain drive, self-lubricating double action pump was used.

The water line consisted of a 1" pipe in 20-foot lengths.

Tools and appurtenances ordinarily used in core drilling operations.

Geologic Features:

The rock in the area of the Hicaco Dam site, Km. 17.2, Mameyes - Rio Blanco Road is mostly a quartz-diorite rock. This is a coarse, cristalline rock, composed mainly of plagiosloise feldspar, hornblende and quartz with small amounts of biotite and pyrite. The rock has a granitic texture. On the basis of the rock mineral content, it appears to have a degree of hardness of 6 on the Moh's scale. The quartz-diorite is quite massive and almost structureless.

The area is thickly covered with vegetation, thereby not disclosing other geologic features except in stream channels and road cuts.

Drilling Operations:

Since the drilling was of a preliminary nature, and due to the lack of proper camp facilities, only one shift was worked per day.

After the moving of the outfits was done, additional personnel was borrowed from the survey crews to carry out the drilling operations.

Method of Operation:

The drilling tools consisted of a cylindrical bit screwed into the end of a cylindrical corebarrel, which in turn is connected by hollow, steel drill rods, passing thru and held firmly by a drive chuck and jaws. This chuck is threaded to a threaded bar or quill. Power is transmitted to the quill from the drill motor to revolve the rods, corebarrel and bit. A water swivel is attached to the top end of the rods. Water is pumped under pressure through the line of rods and the corebarrel, reaching the point of contact between the bit and the rock, then it is forced out of the hole unto the outside of the drilling tool. The swivel is equipped with a bail to which is fastened the hoist cable for handling the drilling tools.

Drill rods are made 1-foot; 2-foot; 5-foot; and 10-foot lengths. Since the travel of the quill is limited to one foot, short rods are used in starting a hole, where there is little or no overburden. As the hole deepens, these shorter sections are replaced with the longer 5-ft. ones and ultimately with 10-ft. rods. Corebarrels vary in length from 22 inches to 10 feet. The outfit is short of 10-ft. sections, therefore the 5-ft. sections were mostly used.

Diamond Drilling: The first operation consists in drilling thru the overburden with a hardened steel fish-tail bit, better known as a saw-tooth bit. Water is then forced by pressure into the hole.

Drilling may continue until rock is encountered, or until the depth of the overburden is such, that caving in of soil, wedges against the corebarrel, or that the water forced into the rods finds its way through boulders, caverns, etc. and seeps down below. Driving in of the casing through the bore hole then commences. This operation is done by dropping a 350-lb. drive hammer on the upper end of the casing. The operation is continued until the lower end of the casing is well seated into the solid stratus.

Casing diameters vary from 2" to 3". The 2" casing, having a smaller cross- sectional area, increases the velocity of the discharged water forcing out the sand and gravel to a better advantage.

After the casing has been properly seated on the rock the drilling machine is set up over the top of the pipe and the line of drill rods, with bit and core-barrel attached, extending down thru pipe to the rock.

After a seat of sufficient depth is obtained, in such a way that it excludes the sand from running in under the casing, and cleaning through of sand and gravel from the casing is accomplished, the saw tooth bit is removed. Then the diamond is lowered into the hole and actual drilling is started.

The diamond bit is a circular steel bit set with either diamonds or bortz. Size "AX" bits and corebarrels were used on this job which recovers a 1 1/8" core.

The bit is attached to the lower end of the corebarrel with a core shell (reaming) connection. The line of rods are fastened to the other end of the corebarrel. The drilling machine is capable of transmitting a rotary speed up to 1500 R.P.M. to the line of rods, core-barrel and bit, and at the same time exerts sufficient pressure on the bit for cutting the rock.

In drilling this formation the rotary speed of the machine was about 1200 R.P.M. Since the core drill is of the screw feed type the pressure in lbs. could not be determined. This rotary action of the bit results in the cutting or wearing away of the rock and this produces a cylindrical core which passes into the core-barrel as the drilling machine forces the drill rods downward. When the drilling tool is taken out periodically for the purpose of removing the core from the corebarrel, a core spring or core lifter is put in the bit, pressing like a wedge against the core to prevent this from dropping out of the barrel.

Sometimes these core lifters are either too tight or too weak. In the latter case, the core may stay down when pulling out the barrel. In the former case, the core may be crushed resulting in a few inches of core loss. An inexperienced operator may report such a loss as a seam, joint, etc. when in reality the rock was sound throughout.

When drilling, the bit is cooled by water forced under pressure through the hollow drill rods.

After the core has been removed from the corebarrel it is marked as to depth and boxed in proper sequence for future study and examination.

The drilling tools are again put down into the hole and the work is continued until the required depth has been attained.

Dam Site Abutment Drilling:

Nine holes were drilled in the dam site abutments, 4 on the left and 5 on the right. No major difficulties were encountered in any of the abutment drillings.

Drilling operations at one of the top ridges of the left abutment were discontinued when rock was found under 144.0 feet of overburden. No rock drilling was done in this hole.

Core drilling in the vicinity of the left abutment required casing work from ground elevation down to the rock. The material from ground surface to bed rock was a residual soil (sandy clay).

Within the limits of the dam excavation there was an average of 44 ft. of overburden. Results obtained from all drill holes are shown on the accompanying drawing: "Topography at Proposed Damsite - Location and Log of Drill Holes".

The only difficulty encountered during the drilling was that of passing through boulders down to foundation rock. In all cases cement grouting was injected to fill in the spaces between the boulders and the rock. This kept the sand out where casing could not be driven down to foundation rock. The life of the diamond bit was therefore increased, since drilling in waste water with a sand content ruins it.

A total of 1071 linear feet was drilled on the damsite abutments. Actual drilling operations were completed July 5, 1945. The equipment was then moved to El Verde Site to begin foundation explorations there. The drilling machine was moved under its own power, and sometimes by the field crew, depending on the type of surface over which it was moved.

Operating Crew:

The drills were operated an average of a 9-hour shift daily five days per week. Each crew consisted of one driller at $0.90 per hour; one helper at $0.70 per hour; and one laborer at $0.30 per hour. Common laborers' wage scale was $0.25 per hour.

Performance:

Diamond Drill: In Table 1 is shown the performance data relative to diamond drilling. Bortz was used as the cutting medium. It is expected that the diamond bits used on this job will be used somewhere else, where the rock may not be as hard as the quartz-diorite found here. At the time when this report was being prepared two diamond bits used at Hicaco Damsite have drilled an average of fifty additional feet each at El Verde Site.

Delays: Time losses as shown amount to about 38.7% of the gross time required for the operations. This was due mostly to heavy rains, since this is an area of high precipitation. Operations were continued under slight rains, otherwise the time lost due to bad weather would have being 20 times greater. Other delays were due to blasting operations, or to lack of water supply, etc.

Costs:

Core drilling costs for period covered by this report are shown in Table I and II.

Drill depreciation for the purpose of this report are taken on the basis of an expected life of 50 months, which amount to 2% of the purchase price ($5000.00 estimated) per month.

Cost per foot of hole as follows:

Damsite abutment holes $3.15

The cost of all drilling during the period of this report was $3,372.00 or an average cost of $3.19 per foot of hole.

The drill operators on the job were Jaime Bujosa, Máximo Santiago and Federico Gregory.

This report was written by Rafael Reyes, Associate Engineer in charge of the exploration work. The performance cost data were compiled from field records.

T A B L E I

Diamond Core Drilling Performance

(May 2 to July 5, 1945)

	Dam Abutments 1 1/8" holes
Gross Operating Hours	744
Delay Hours	
Moving	130
Transportation	122
Mechanical	21
Bad Weather	7
Miscellaneous	7
Total Delays	287
Net Operating Hours	457
Delays ....% of Gross Hours	
Moving	17.5%
Transportation	16.4
Mechanical	2.8
Bad Weather	1.0
Miscellaneous	1.0
Total Delays	38.7%
Total Feet Drilled	
Overburden	686
Solid Bed Rock	385
Total	1071
Total Feet per Gross Hour	1.44
Total Feet per Net Hour	2.38
Bits (Bortz) Total used	17
Average footage per bit (rock only)	33

T A B L E II

Core Drilling - Hicaco Dam

TOTAL COST OF ALL DRILLING

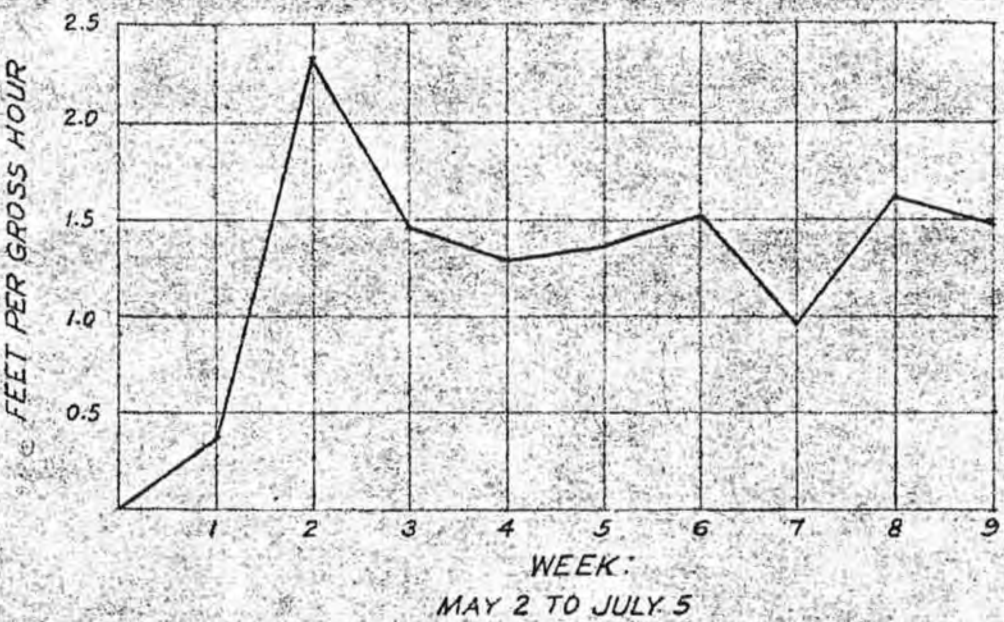
(May 2 to July 5, 1945)

Gross Operating Hours	744
Net Operating Hours	457
Delay Hours	281
Total Linear Feet Drilled	1071

	Total Cost Entire Drilling	Cost per ft. of drilling
1. Operation	$ 2,042.00	$ 1.903
2. Maintenance	500.00	.467
3. Repairs	100.00	.093
4. Supplies	300.00	.279
5. Depreciation	430.00	.401
Grand Total of all Drilling Expenditures	$ 3,372.00	$ 3.143

These costs are complete with exception of:

1. Engineering & Construction office overhead
2. Compensation insurance
3. Transportation depreciation
4. Miscellaneous supplies brought from Caonillas, etc.



PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DIVISION

HICACO RIVER PROJECT
CORE DRILL PERFORMANCE

SUBMITTED	RECOMMENDED	APPROVED
SAN JUAN, P. R.	JULY 28, 1945	

DRAWN

TRCD A. E. S.

CHKD

San Juan, P. R.

August 17, 1945

To: Mr. Carl A. Bock
Chief Engineer

From: Rafael Reyes

Re: Hicaco Dam

Enclosed herewith is submitted final report of the preliminary foundation explorations at Hicaco Dam, Km. 17.2, Mameyes, Rio Blanco Road.

This report supplements that of the drilling report submitted July 28, 1945.

Rafael Reyes
Associate Engineer

RR:rjr

PUERTO RICO WATER RESOURCES AUTHORITY
Engineering and Construction Division

Hicaco River Project — Surveys and Foundation Exploration Section

Foundation Explorations Report

by

Rafael Reyes
Associate Engineer
in Charge of Explorations and Surveys.

August 13, 1945 — San Juan, Puerto Rico

Inspection Excavations - Hicaco Dam Site; Km. 17.2
Mameyes - Rio Blanco Road

Carl A. Bock, Chief Engineer

Robert C. Price, Head Engineer

SUMMARY

Foundation Explorations involving excavation of only one test pit was conducted at Hicaco Dam.

Period from June 24 to July 5, 1945

The test pit was excavated to a depth of 20.5 ft.

Cost per cubic yard of excavation ....$ 5.10

These costs include labor and direct engineering supervision. Local timber was used at no cost. They are final field costs and correct within 2% margin.

Introduction - This report describes, in general, excavation operations for inspection purposes and summarizes results obtained and shows excavations costs, on foundation exploration at Hicaco Dam, Km. 17.2, Mamoyes - Rio Blanco Road, covering the period from June 24 to July 5, 1945. This work was conducted simultaneously with core drilling and information given herein supplements that of the drilling report (Hicaco Dam) submitted July 30, 1945.

Equipment -

Power from the core drilling machine. The power from the core drill was used simultaneously and without interruption of the drilling operations.

Hoist: The hoisting device of the core drill was used during the excavation of the pit.

Miscellaneous: Other equipment consisted of pick and shovels; half of an empty gasoline drum used as a bucket to remove the earth, a 7 ft. 2" pipe tripoid, pulleys, and 100 ft. 1" diameter manila rope.

Excavation conditions -

The pit was dug at a ground elevation of 2055 ft. on the right abutment and about 60 ft. upstream from the dam axis. Excavation was confined to the overburden material, soft enough to be dug with pick and shovel. This overburden is residual soil.

A 5' x 5' (overall) section was started at the location given above, and carried down to a depth of 20.5'. Rock was found at this depth. The pit was timbered its entire depth. Although the material is rather compact, with no occurrence of sloughing or caving, it was thought advisable to install a skeleton type of timbering as an added factor of safety.

General information obtained -

The overburden showed complete weathering down to foundation rock. The material is quite imperveous. The top 6 feet of the overburden showed the material to be friable clay, with some degree of plasticity to no plasticity at all with increase in depth.

The overburden showed complete weathering down to foundation rock.

Earth samples equivalent to 1/40 cubic feet were bottled and sent over to Caonillas Project for laboratory tests.

1. Effect of Water on the Material: No sloughing, slumping or caving of the side walls of the pit resulted from the action of the water during the first 48 hours.

2. Leakage in Relation to Volume of Pit: In pumping water into the pit at the rate of 31 G. P. M. the head could be built up to the point of overflow.

3. Leakage in Relation to Head: In the enclosed saturation curve, it is shown that the increment rate of saturation was about 1.5 gals per minute up to a head of 8 ft. From this head on, the increment rate of saturation was kept rather constant, up to the point of overflow, and equals to 0.5 gallons per minute. This shows the material to be quite imperveous.

Costs - A tabulation of cost per cubic yard is given in Table I which is the last page of this memo. These figures are found on laborer's rate of pay of $0.25 per hour.

Comments - No faults, fissures or major points were found in the excavation of this pit. Therefore, it is assumed this is a weathered zone of practically complete oxidation and since the ridge is sufficiently massive to be stable against the hydrostatic pressure produced by the impounded water of the dam, the only undesirable factor of the deep weathering is the possibility of percolation.

Sheet piling - Could not be driven here with satisfaction as the boulders found during drilling will not permit complete penetration into the lower stratum.

This report was prepared by Rafael Reyes, Associate Engineer in charge of the exploratory work.

RR:rjr

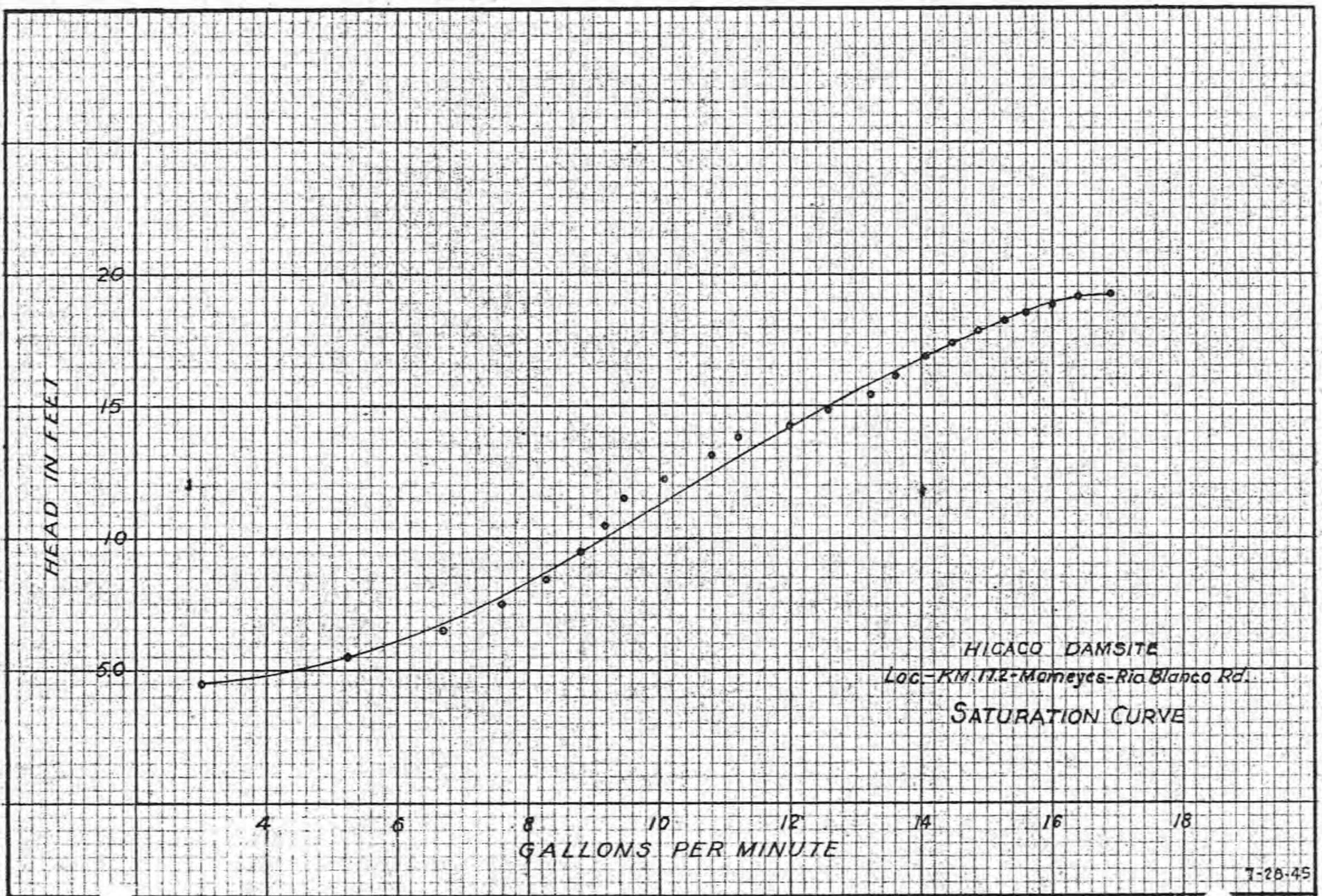
TABLE I

Excavation Costs

	Total Excavations (Cu. Yd.)	Total Cost	Excavation Cost per cu. yd.	Timbering cost per cu. yd. exc.
Test Pit No. 1	19	$98.92	$5.10	-----------

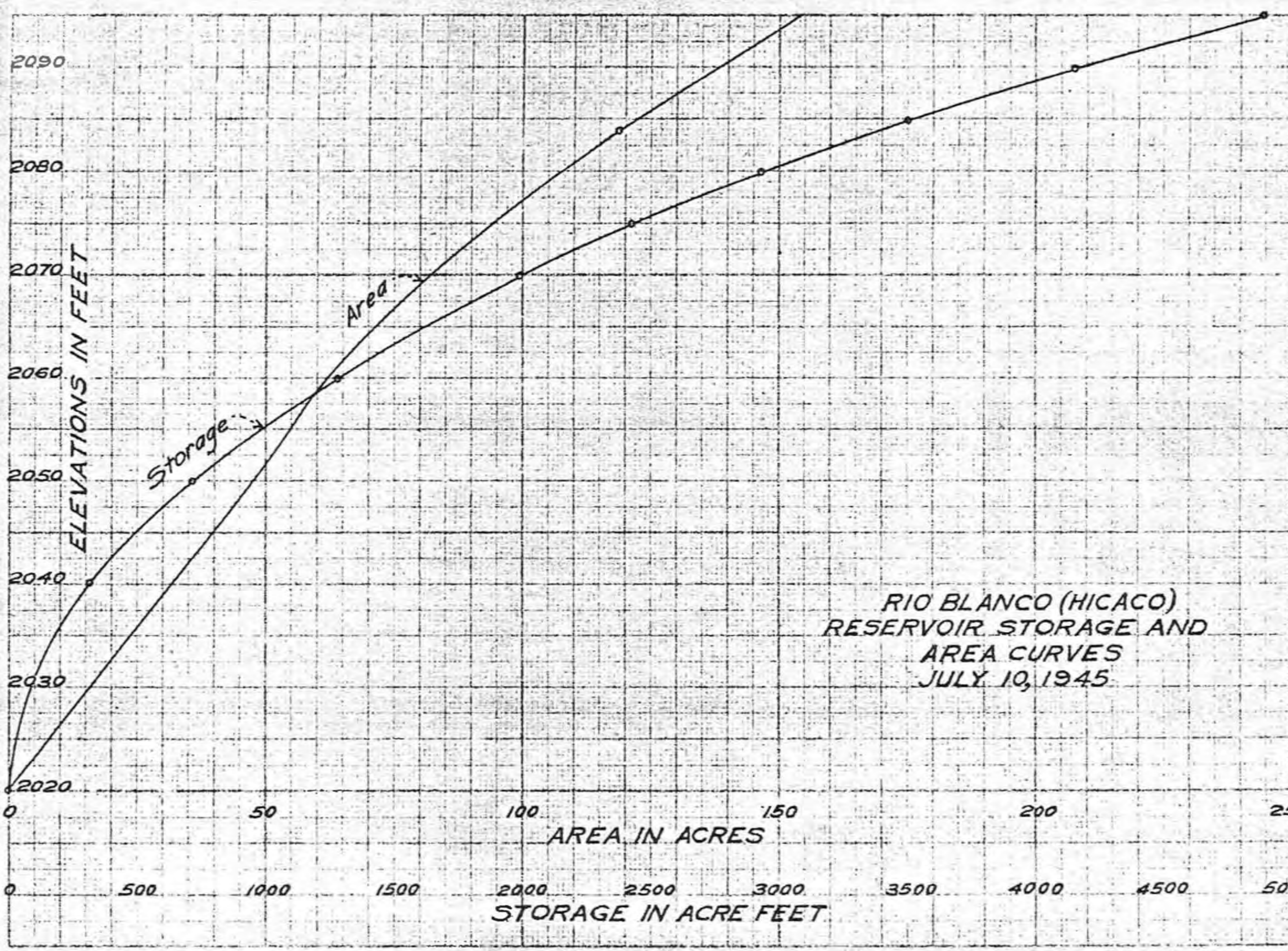
This cost is complete with exception of:

1. Engineering and construction office overhead.
2. Compensation insurance.
3. Transportation depreciation.



HEAD IN FEET
20
15
10
5.0
4
6
8
10
12
14
16
18
GALLONS PER MINUTE
HICACO DAMSITE
Loc.-KM.17.2-Mameyes-Rio Blanco Rd.
SATURATION CURVE
7-28-45

APPENDIX "B"



ELEVATIONS IN FEET
2090
2080
2070
2060
2050
2040
2030
2020
Area
Storage
0
50
100
150
200
250
AREA IN ACRES
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
STORAGE IN ACRE FEET
RIO BLANCO (HICACO)
RESERVOIR STORAGE AND
AREA CURVES
JULY 10, 1945

Exhibit No. 1

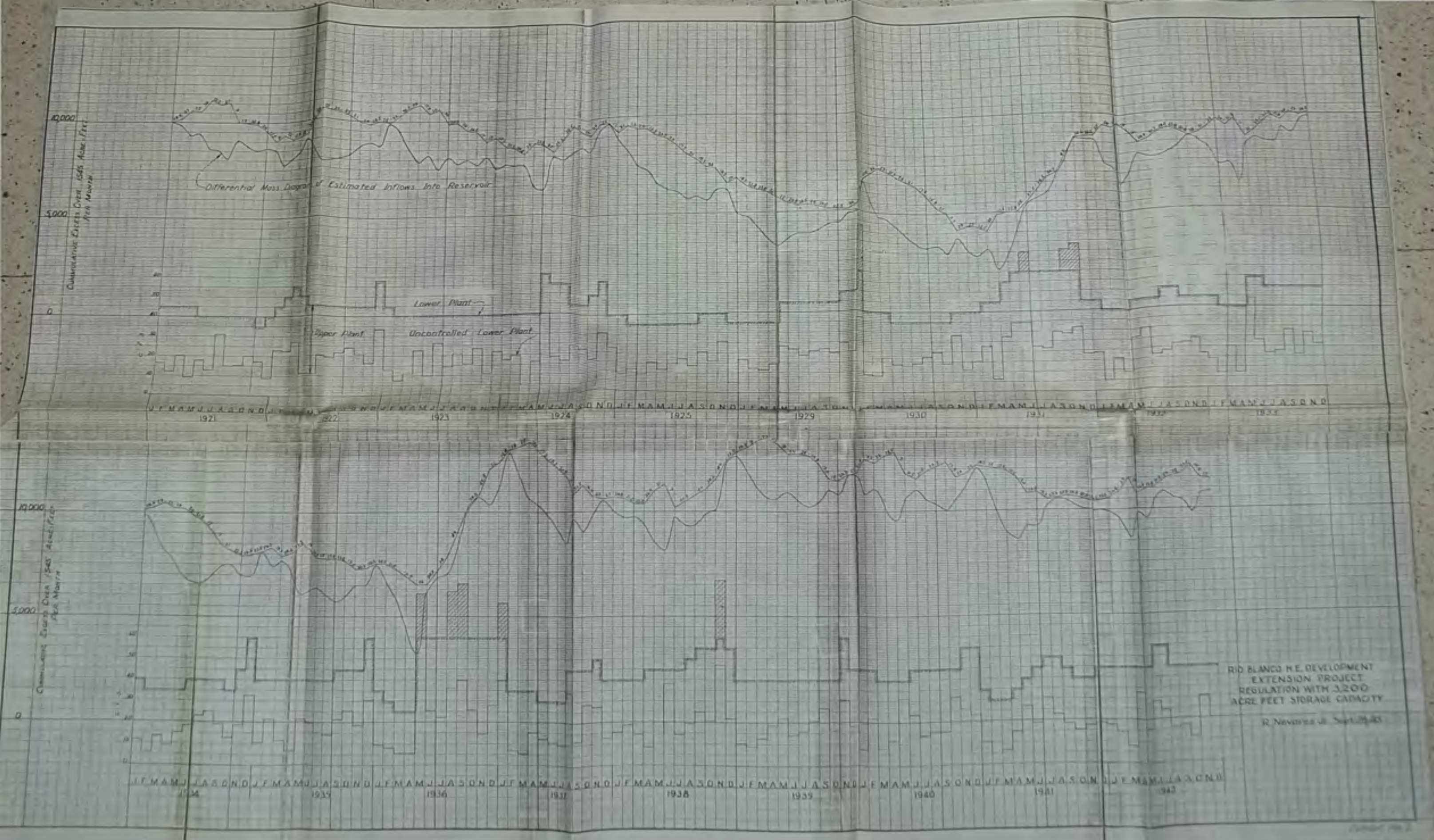
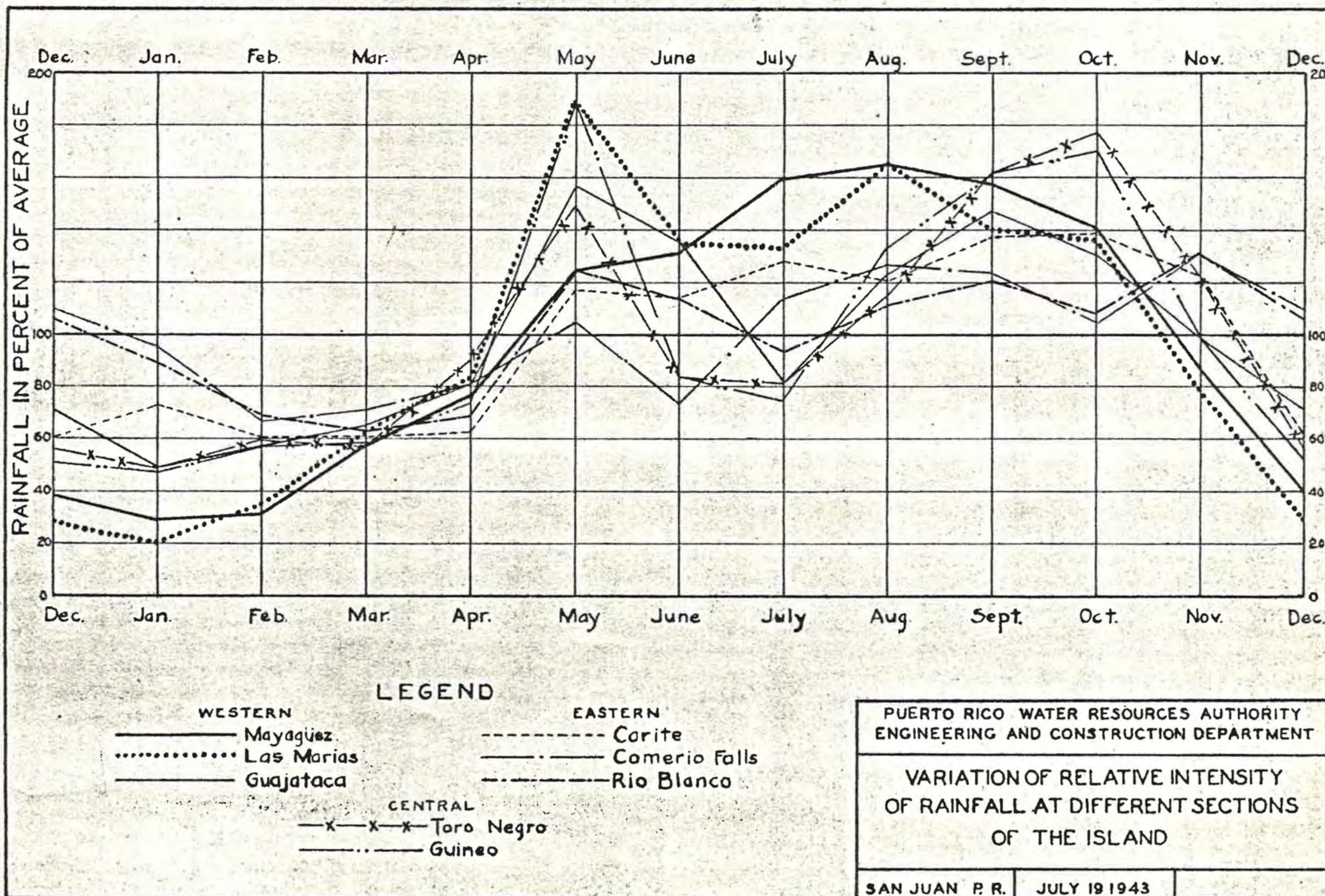
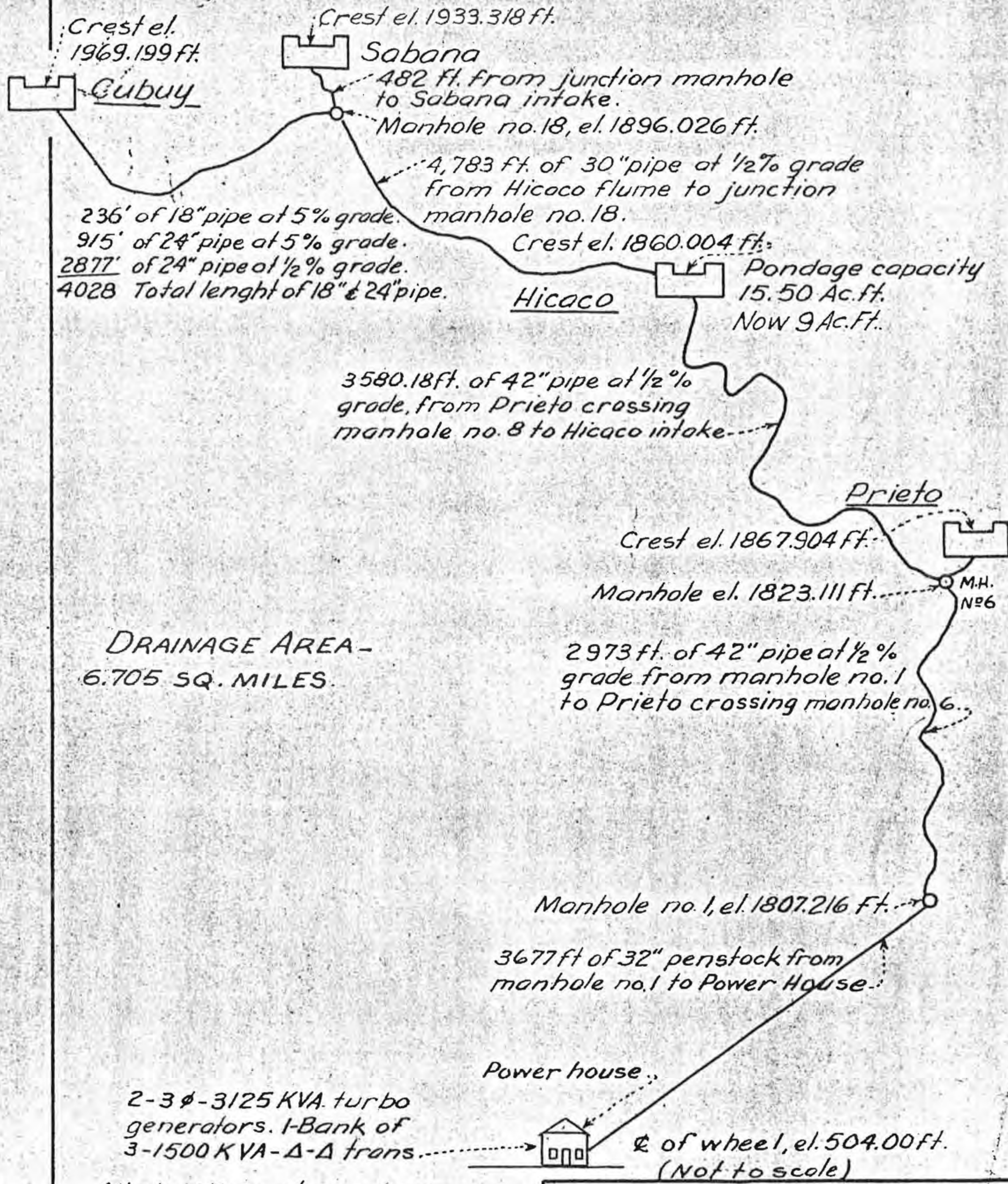

Cumulative Excess Over 1545 Acre Feet Per Month
10,000
5,000
0
Differential Mass Diagram of Estimated Inflows Into Reservoir
Lower Plant
Upper Plant
Uncontrolled Lower Plant
1921
1922
1923
1924
1925
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
RIO BLANCO H.E. DEVELOPMENT
EXTENSION PROJECT
REGULATION WITH 3,200
ACRE FEET STORAGE CAPACITY
R. Nevares Jr. Sept. 29, 40

Exhibit No. 3


Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
RAINFALL IN PERCENT OF AVERAGE
200
100
80
60
40
20
0
LEGEND
WESTERN
Mayagüez
Las Marias
Guajataca
EASTERN
Carite
Comerio Falls
Rio Blanco
CENTRAL
Toro Negro
Guineo
PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DEPARTMENT
VARIATION OF RELATIVE INTENSITY
OF RAINFALL AT DIFFERENT SECTIONS
OF THE ISLAND
SAN JUAN P. R.
JULY 19 1943



All elevations shown are
refered to 500 ft. datum
at power house.

NOTE:-
TRACED FROM
P.R.R.L & P. CO. DWG. M-4137

PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DEPARTMENT

GENERAL LAYOUT OF EXISTING
RIO BLANCO PROJECT

SAN JUAN P.R. | OCT. 5, 1942.

Exhibit No. 4

Table I

MOUNTAIN STREAMS

Average Recorded Rainfall & Runoff

Streams	Elev.	Drainage Area in Sq. Mi.	Years of Record	Average Yearly Rainfall in inches	Average Yearly Run-off in Ac. Ft.	Average yearly Ac. Ft. per sq. mile per inch of rainfall	Coefficient of Runoff
Toro Negro River (at Guineo Res.)	2900	1.57	14	105.66	7205 *	43.43	81.80%
Matrullas River	2400	4.42	14	85.16	16,397 *	43.57	82.00%
Vacas River	2400	6.60	16	94.70	21,900 **	35.04 **	65.80%
La Plata River (at Carite Res.)	1780	7.92	34	81.30	31,268 *	48.50	91.00%
						Ave.	80.15

* Runoff in these streams were measured as inflows to storage reservoirs by recording elevations of water in reservoirs and spillway discharges. They include peaks which would not be recorded by weirs or other methods.

** These records do not include large peaks which were not measured by gaging station.

TABLE II

ANALYSIS ON THE SPILLINGS AT HICACO DIVERSION DAM

Year	Spillings Ac. Ft. (Hicaco)	Equivalent Rainfall in Inches	Rainfall at Hicaco Dam	Actual Utilization (Inches at rainfall)	Spillings plus Utilization (Inches)	Losses Inches
1940	7587	46.13	150.79	58.36	106.49	44.30
1941	8191	51.97	132.20	55.03	107.00	25.20
1942	9950	63.13	152.42	62.89	126.02	26.40
1943	8825	56.00	163.95	62.60	118.60	45.35
1944	8762	55.59	170.71	60.20	115.79	54.92
Total	43315	274.82	770.07	299.08	573.90	196.17
Average	8663.0	54.96	154.01	59.81	114.78	39.23

TABLE NO. 3

Rainfall Records - Rio Blanco 1800 Ft.

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1921	----	----	13.28	6.21	11.65	8.59	20.49	9.90	10.15	13.32	11.41	5.96	
1922	15.14	14.81	17.75	7.43	7.24	13.41	12.86	14.36	16.08	13.86	10.83	21.94	165.71
1923	8.60	5.01	7.38	14.92	6.48	17.27	9.53	13.81	10.30	15.38	7.27	14.26	130.21
1924	11.59	12.73	3.32	10.71	26.37	12.19	10.75	15.86	14.63	10.71	20.40	15.06	164.32
1925	5.92	7.91	6.00	10.27	7.10	9.77	11.38	9.13	13.59	10.53	16.80	2.74	111.14
* 1929										5.56	16.46	10.39	
1930	24.31	5.73	5.38	11.18	9.01	8.60	9.41	11.39	13.02	9.23	18.67	7.29	133.22
1931	9.98	14.92	4.21	17.98	22.70	22.58	14.82	14.33	19.55	18.94	20.75	12.13	192.89
1932	12.32	2.42	10.43	5.90	17.23	19.75	11.04	12.22	----	14.59	16.08	11.13	147.11
1933	9.16	4.73	13.17	4.79	27.93	15.35	10.96	11.75	18.55	10.51	17.78	14.03	158.73
1934	7.55	3.94	8.83	6.10	9.74	11.99	15.15	16.37	12.65	8.32	12.25	21.42	135.31
1935	7.19	14.08	7.56	4.36	13.99	13.10	9.92	9.49	14.11	16.82	12.39	19.98	142.99
1936	6.34	5.50	1.08	2.72	36.26	16.67	14.66	23.78	26.18	16.91	9.41	18.37	177.86
1937	26.29	3.41	3.56	9.97	7.99	7.07	6.24	22.42	7.62	18.64	17.82	8.45	139.58
1938	10.16	12.44	9.50	5.45	9.27	25.11	9.39	12.71	16.41	13.61	31.12	14.39	169.56
1939	6.74	5.91	8.46	12.35	14.54	9.26	10.39	13.59	17.42	10.51	19.93	11.82	140.92
1940	5.00	14.54	5.31	7.56	20.51	15.54	8.98	10.25	10.19	20.78	17.10	15.03	150.79
1941	6.98	1.28	4.22	9.79	17.52	12.35	20.20	15.01	11.06	10.03	11.47	12.29	132.20
1942	11.69	9.40	5.18	21.63	10.16	19.00	16.00	10.53	11.00	7.63	19.82	10.28	152.32
1943	12.93	6.80	10.48	13.05	20.95	15.28	13.12	19.61	11.82	25.88	8.30	11.26	169.48
1944	8.64	6.09	2.75	6.89	13.94	26.00	20.31	20.90	19.00	19.27	10.16	13.00	166.95
1945	4.82	10.01	6.47	15.63	17.03	8.76	18.07	13.77	13.76	10.76	9.41	3.00	131.49
Sums	211.37	161.66	153.92	204.89	327.61	307.58	273.67	301.18	287.07	301.79	335.73	274.22	
Means	10.57	8.08	7.33	9.76	15.60	14.65	13.03	14.34	14.35	13.72	15.26	12.46	149.15

Dry Season = 12.46 + 10.57 + 8.08 + 7.33 + 9.76 = 48.20 = 32.31% of total.
Wet Season = 15.60 + 14.65 + 13.03 + 14.34 + 14.35 + 13.72 + 15.23 = 100.95 = 67.69% of total.

* No record from 1926 to 1928 inclusive.

TABLE NO. 4

Rainfall Records - La Mina

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1935	9.43	19.96	7.08	7.27	18.21	21.10	17.70	14.71	17.82	23.65	19.58	26.67	203.18
1936	9.37	7.12	3.79	3.01	40.40	19.52	19.86	36.61	29.12	37.17	15.19	32.63	253.79
1937	39.75	8.53	5.02	11.44	3.38	11.86	10.68	19.89	9.07	16.79	20.07	12.37	170.85
1938	12.39	11.00	12.92	9.44	14.33	31.93	11.91	18.91	19.42	14.60	35.76	16.09	208.70
1939	8.54	7.42	10.94	8.29	18.51	10.37	12.53	16.01	16.81	12.10	27.24	14.11	162.87
1940	9.94	25.56	7.44	7.05	26.00	14.79	8.34	12.94	7.72	18.77	18.78	13.56	170.89
1941	8.58	1.26	7.02	14.97	26.07	15.44	11.20	18.06	10.37	12.54	11.68	9.53	146.72
1942	14.43	14.39	3.84	14.47	4.87	23.38	17.35	11.11	12.50	9.34	22.78	14.32	162.78
1943	21.04	8.74	10.13	---	27.53	20.94	16.84	19.14	13.68	7.92	10.04	14.90	170.90
Sums	133.47	103.98	68.18	75.94	179.30	169.33	126.41	167.38	136.51	154.88	181.12	154.18	1650.68
Means	14.85	11.57	7.58	9.49	19.94	18.83	14.05	18.62	15.20	17.20	20.15	17.15	184.63

TABLE NO. 5

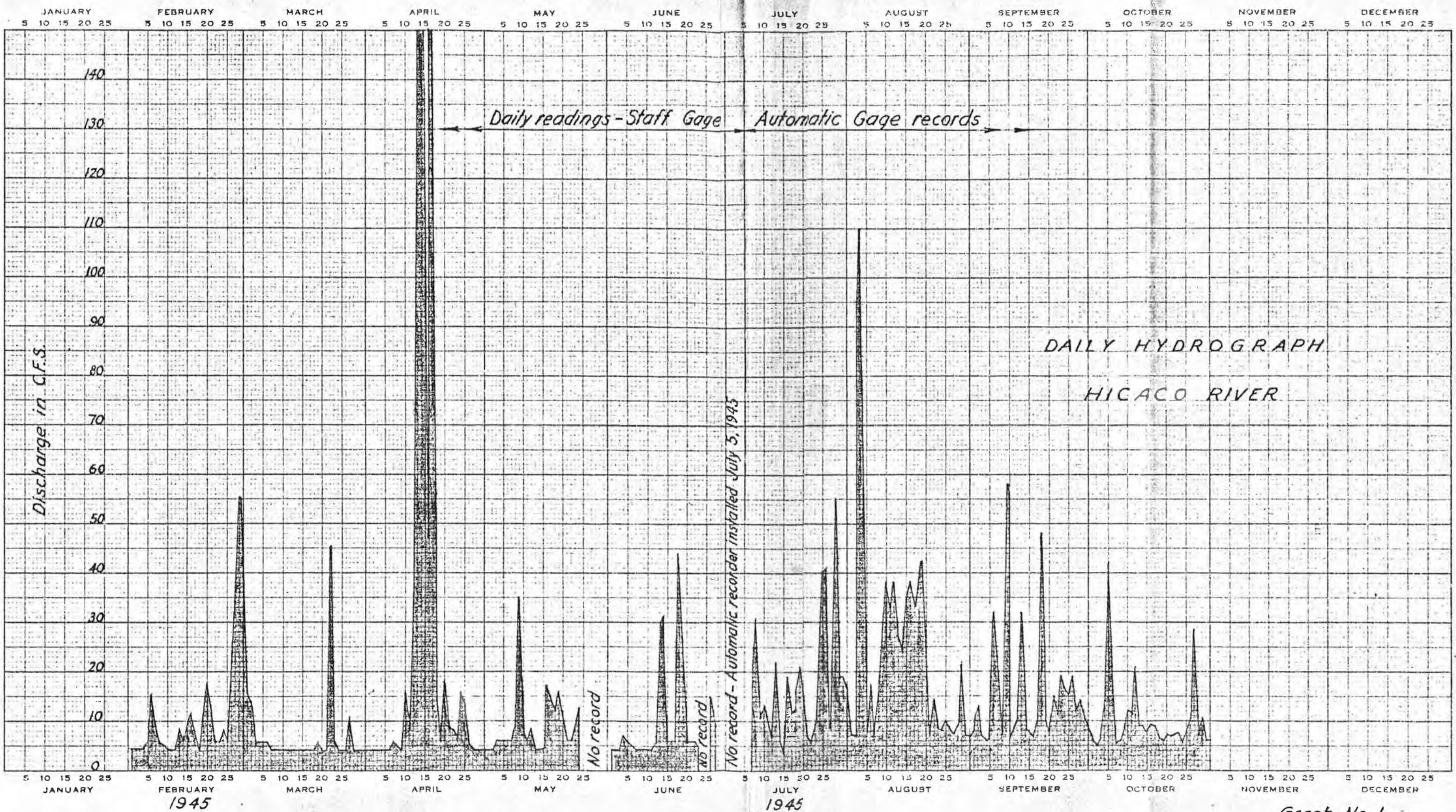
POWER PRODUCTION

RIO BLANCO PLANT

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1936	1,723,600	1,667,600	708,400	720,200	1,761,700	2,238,400	1,467,900	1,147,000	1,475,100	1,386,000	1,390,100	1,955,700
1937	727,000	1,807,300	1,338,400	1,677,000	1,557,600	1,364,600	1,197,900	1,967,400	1,494,400	1,808,700	1,703,400	2,017,100
1938	2,207,000	1,667,100	1,447,100	1,433,800	1,641,200	2,111,900	1,848,000	1,813,800	1,977,500	1,908,600	2,132,000	1,988,600
1939	1,913,700	1,498,800	1,671,900	1,799,900	2,116,800	1,805,400	1,730,800	2,019,100	1,981,400	1,877,600	2,004,600	1,810,400
1940	1,483,300	1,815,400	1,380,400	1,401,300	2,019,100	2,140,100	1,730,800	2,019,100	1,981,400	1,877,600	2,004,600	1,810,400
1941	1,483,300	1,815,400	1,380,400	1,401,300	2,019,100	2,140,100	1,886,700	1,668,000	1,601,600	2,433,500	2,172,700	2,270,400
1942	1,703,600	775,100	926,300	1,228,000	1,866,400	1,745,000	2,341,100	2,422,700	1,998,600	1,950,600	2,097,400	2,311,200
1943	2,357,700	1,513,100	1,182,500	2,004,200	1,483,100	2,488,800	2,466,200	1,964,000	1,945,500	1,677,900	2,115,400	2,406,100
1944	2,462,400	1,712,800	1,696,400	1,743,300	2,199,400	1,910,700	2,176,500	2,469,000	2,108,700	2,387,400	1,814,500	1,989,400
1945	1,717,500	1,354,300	772,200	994,700	1,329,800	2,310,900	2,356,700	2,337,500	2,394,000	2,026,400	1,676,200	
TOTAL	17,779,100	15,626,900	12,504,000	14,403,700	17,994,200	20,255,900	19,202,600	19,827,600	18,958,200	19,334,300	19,110,800	18,559,200
AVE.	1,777,910	1,562,690	1,250,400	1,440,370	1,799,420	2,025,590	1,920,260	1,982,760	1,895,820	1,933,430	1,911,080	2,062,130

Dry season monthly average = 1,618,700 KWH

Wet season monthly average = 1,924,050 KWH



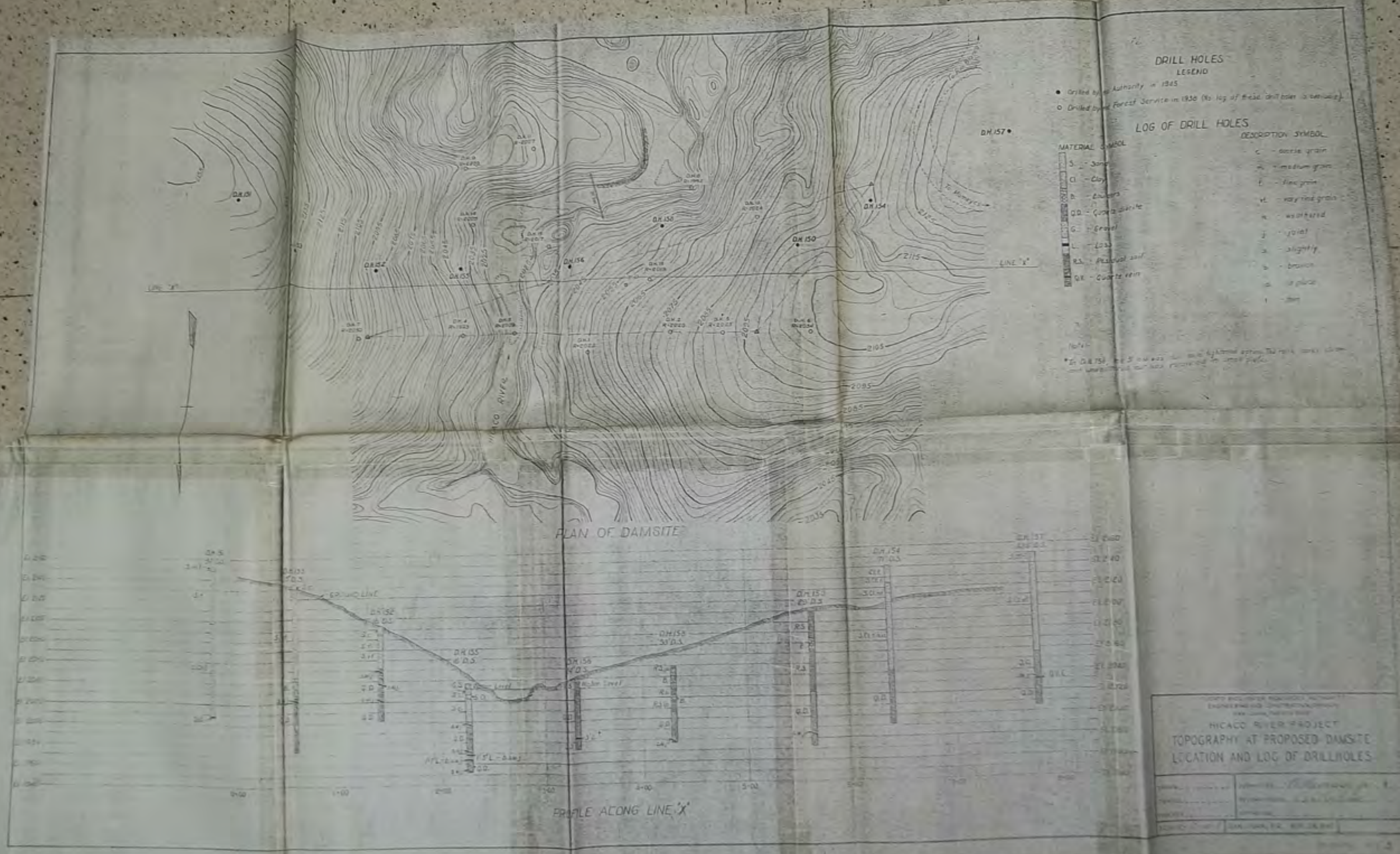
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
Daily readings - Staff Gage
Automatic Gage records
Discharge in C.F.S.
No record
No record
No record - Automatic recorder installed July 5, 1945
DAILY HYDROGRAPH
HICACO RIVER
1945
1945

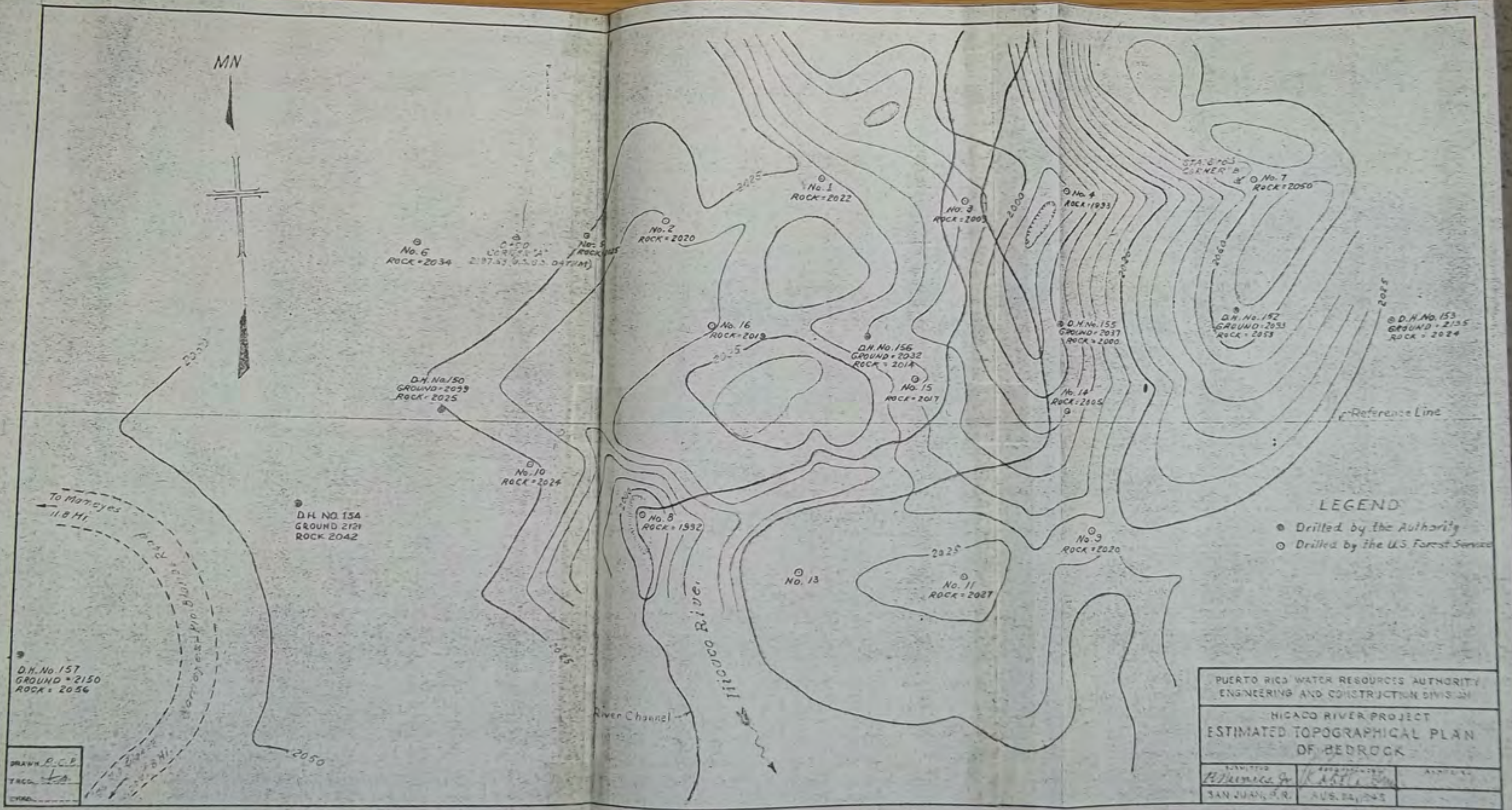
Graph No. 1

APPENDIX "C"

La Mina
Rain Gauge
TO NAGUABO
PROPOSED DAM
PROPOSED RIO BLANCO PLANT NO. 2
Rain Gauge
EXISTING RIO BLANCO PLANT NO. 1
Rain Gauge
TO RIO BLANCO
GENERAL PLAN OF PROPOSED DEVELOPMENT
SCALE: 1:20,000
ELEVATION IN FEET
PROPOSED ICACO DAM
EXISTING CUBUY DIV. DAM
EXISTING SABANA DIV. DAM
PROPOSED RIO BLANCO PLANT NO. 2
EXISTING ICACOS DIV. DAM
EXISTING PRIETO DIV. DAM
CUBUY RIVER
SABANA CREEK
PRIETO RIVER
BLANCO RIVER
ELEV. 104±
EXISTING RIO BLANCO PLANT NO. 1
GENERAL PROFILE
SCALE:- HOR. 1" = 2,000 FT.
VERT. 1" = 400 FT.
ATLANTIC OCEAN
N
SAN JUAN
ISLAND OF PUERTO RICO
CARIBBEAN SEA
LOCATION MAP
SCALE: 1":760,000
GENERAL PLAN, PROFILE AND
LOCATION MAP

"LA MINA"
RAIN GAGE
YUNQUE NATIONAL RESERVE
PROPOSED
HICACO DAM
HICACO RIVER
STA 580
DRAINAGE AREA
PROPOSED HICACO
H.E. PLANT NO 2
CUBUY RIVER
SABANA
PRIETO R.
RAIN GAGE
RIO BLANCO
H.E. PLANT
N
LEGEND
RAINFALL GAGING STATION
STREAM GAGING STATION
DRAINAGE AREA
28 SQ MILES
PEÑA POBRE
ROAD 23
NAGUABO
BLANCO
RIVER
VIEQUES PASSAGE
PLAN OF BASIN
3000
2000
1000
ELEVATION - M.S.L.
FEET
PROPOSED DAM
SPILLWAY CREST EL 2084
PROP. H.E. PLANT Nº 2
(HICACO DIVERSION)
H.E. PLANT NO. 1
10000
20000
30000
40000
50000
OCEAN
DISTANCE IN FEET
RIVER PROFILE
SCALE 1:50,000
PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DIVISION
RIO BLANCO RIVER BASIN
PLAN AND RIVER PROFILE
SAN JUAN, P.R.
Drawing No. 2


DRILL HOLES
LEGEND
LOG OF DRILL HOLES
MATERIAL SYMBOL
DESCRIPTION SYMBOL
S. - Sand
Cl. - Clay
G. - Gravel
R.S. - Residual soil
c - coarse grain
m - medium grain
f - fine grain
vf - very fine grain
w - weathered
j - joint
s - slightly
b - brown
Note:-
D.H.157
D.H.154
D.H.150
D.H.156
D.H.152
D.H.155
D.H.151
LINE "X"
PLAN OF DAMSITE
GROUND LINE
PROFILE ALONG LINE "X"
HICACO RIVER PROJECT
TOPOGRAPHY AT PROPOSED DAMSITE
LOCATION AND LOG OF DRILLHOLES


MN
No. 6
ROCK = 2034
CORNER "A"
No. 5
No. 2
ROCK = 2020
No. 1
ROCK = 2022
No. 3
ROCK = 2003
No. 4
ROCK = 1993
No. 7
ROCK = 2050
CORNER "B"
No. 16
ROCK = 2019
D.H. No. 156
GROUND = 2032
ROCK = 2014
No. 15
ROCK = 2017
D.H. No. 155
GROUND = 2037
ROCK = 2000
No. 14
ROCK = 2005
D.H. No. 152
GROUND = 2093
ROCK = 2053
D.H. No. 153
GROUND = 2135
ROCK = 2024
D.H. No. 150
GROUND = 2099
ROCK = 2025
No. 10
ROCK = 2024
D.H. NO. 154
GROUND 2121
ROCK 2042
To Maunabo
No. 8
ROCK = 1992
No. 13
No. 11
ROCK = 2027
No. 9
ROCK = 2020
D.H. No. 157
GROUND = 2150
ROCK = 2056
Reference Line
River Channel
Hicaco River
2025
2000
2050
LEGEND
Drilled by the Authority
Drilled by the U.S. Forest Service
PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DIVISION
HICACO RIVER PROJECT
ESTIMATED TOPOGRAPHICAL PLAN
OF BEDROCK
SAN JUAN, P.R.

Drawing No. 4

Top of Parapet Elev. 2094
Spillway Crest Elev. 2084
Slope 2:1
Elev. 2020
Elev. 2094
Elev. 2025
Diversion Conduit
Intake Str.
Line X
SPILLWAY SECTION
NON OVERFLOW SECTION
PLAN OF PROPOSED DAM
Scale - 1" = 40'-0"
390' Dam
40'
50'
Top of Parapet Wall Elev. 2094
Top of Abutment Elev. 2090
Spillway Crest Elev. 2084
100'
Spillway
Backfill Slope 2:1
Orig'nal Ground Line
Diversion Conduit
Estimated Rock Profile
ELEVATION
PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DIVISION
HICACO RIVER PROJECT
HICACO DAM
PLAN, ELEVATION AND SECTION
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
SCALE: AS NOTED
Drawing No. 5

A P P E N D I X "D"

GEOLOGY OF THE HICACO DAM SITE

Report of Mr. Robert A. Laurence, Geologist. September 28, 1943.

Introduction

The site of the proposed Hicaco dam is on Hicaco River, a tributary of the Rio Blanco system, at kilometer 18.35 on the El Yunque road, and approximately 30 miles southeast of San Juan, P. R. The dam and reservoir will be entirely within the Caribbean National Forest. The writer made a brief geological examination of this site on September 24, 1943 at the request of the Puerto Rico Water Resources Authority, and was accompanied in the field by Mr. C. A. Bock, Chief Engineer, and Mr. M. A. Quiñones, Sr. Hydroelectric Engineer, of the Authority.

No preliminary exploration or field surveys have been made yet, but the area is included in the Yunque topographic quadrangle of the U. S. Department of the Interior, Geological Survey, advance sheets of which are available. It also lies in the region known as the Fajardo district, of which a geological report and map by H. A. Meyerhoff and I. F. Smith were published in 1931 as volume 2, part 3, of the Scientific Survey of Puerto Rico and the Virgin Islands, by the New York Academy of Sciences.

Regional Geology

The Luquillo Mountains, one of the highest and most rugged areas in Puerto Rico, are situated in the northeast portion of the island. As a result of this location they receive a very heavy rainfall and support very dense vegetation which effectively obscures the geological features except in stream channels and road cuts. The mountains are composed chiefly of a thick series of volcanic tuffs and agglomerates, and indurated shales. Into these have been intruded, at considerable depth, small bodies of granitoid igneous rocks, chiefly quartz diorite and diorite, which are probably related to, if not actually a part of, the extensive batholith which occupies the area west of Humacao.

Hicaco River flows across one of these intrusive bodies, whose surface extent is about 4 square miles. The dam site is near the middle of the northern portion of this elongated mass.

Local Geology

The only rock exposed at the dam site, and for some distance in all directions from it, is quartz diorite. This is a coarsely crystalline rock,

composed chiefly of plagioclase felspar, hornblende and quartz, with minor amounts of biotite and pyrite. The large (3 to 15 mm.) crystals of hornblende in a groundmass of smaller (2 to 5 mm.) crystals of gray feldspars and quartz, give the rock a conspicuously mottled appearance. The rock also contains large (1 to 10 inches) round inclusions or segregations of dark, fine-textured quartz diorite of similar mineralogic composition, but these are evident only in the larger exposures.

The quartz diorite is quite massive and almost structureless. The only persistent structures observed are some N 70°W joints, and while some of these are continuous for many feet, they are not closely spaced and do not have any noticeable effect upon the rock.

The most conspicuous feature of the rock is the large-scale spheroidal weathering, which is well exposed in the road cuts and in the stream channel. This weathering results in huge rounded masses of quartz diorite, as much as 20 feet in diameter, surrounded, at least on the top and sides, by thin layers of the same rock (1 to 3 inches thick) which lie in concentric bands and resemble thin-bedded sediments which have been folded. This apparent "stratification", however, is entirely a secondary feature developed by weathering, and will not be present in the fresh rock below the surficial weathered zone.

The Dam Site

At the dam site, Hicaco River is flowing at an altitude of about 2000 feet, in a narrow V-shaped gorge which is more than 225 feet deep. At a height of 150 feet above the river, the gorge is only 650 feet wide. Within a quarter of a mile below the dam site, the river falls more than 220 feet, but in the quarter-mile above the site, the fall is only 50 feet.

Bed rock is exposed on the right abutment in the road cuts, and it presents an irregular upper surface, due to the spheroidal weathering mentioned above, however in the exposed areas, the average thickness of clay and badly weathered rock is not much over ten or fifteen feet. It is not likely that excessive excavation will be required, to expose continuous unweathered rock on this abutment.

The river bed, at the dam site, is composed of many large rounded masses of quartz diorite, which are the spheroidal "boulders" from which the surrounding and intervening weathered material has been removed, so that the river now flows around and between the "boulders", some of which rise 10 feet or more above the water level. That these "boulders" are actually bed rock in place is indicated by the fact that many small fine-grained dikes can be traced through several of the "boulders" without any offset or change in direction or position. Thus it is a safe assumption that very little excavation will be required in order to uncover sound rock in the stream channel. The large "boulders", however, are probably underlain by rock which is more weathered than they are.

The left abutment is covered with a dense growth of trees and underbrush, and rock is visible only in the bed of a small but deep tributary ravine. A more or less continuous succession of ledges of quartz diorite, some only slightly weathered and others practically reduced to tosca, extends up this ravine to a height of at least 150 feet above the river. Thus it appears that, while sound rock similar to that on the right abutment, undoubtedly underlies the "nose" which forms the left abutment, it may be under as much as 35 or 40 feet of residual cover. Similarly, in the relatively narrow divide east of the abutment, unweathered rock is probably deep.

Need for Exploration

Only a comparatively small amount of preliminary exploration should be required in order to determine the foundation conditions at this site. A few core drill holes on the right abutment, carried far enough into unweathered quartz diorite to be sure they do not bottom in a spheroidal "boulder" should be sufficient to prove that side. Deep drilling is not necessary, as the quartz diorite is not likely to be weathered to any considerable depth, and where fresh and sound it is as strong and suitable a foundation rock as any on the island.

Several drill holes on the left abutment and along the narrow saddle, 2,500 feet to the east, carried into unweathered rock, will prove conditions in that area. There is no danger of leakage through the unweathered rock, even in narrow portions of the divide, but the thickness and character of the overburden in such areas should be determined. This also applies to the narrow area on the right bank, 1000 feet northwest of the abutment, although there the rim is wider and higher than at the saddle on the left side.

In the areas affected by spheroidal weathering, the apparent "stratification" of the granite will probably affect core recovery, and will cause that which is recovered to come out in small pieces. The angle of dip of the apparent "stratification" should be noted carefully, as the shape and extent of the spheroidal masses and intervening weathered rock can be interpreted from them. Thus, if the apparent "stratification" is vertical, the hole may be interpreted as passing between a large "boulder" and a clay pocket, or between two "boulders", whereas horizontal "stratification" indicates rock immediately above (or below) one of the rounded masses.

Construction Materials

It is probable that a quarry site can be located somewhere along the road, on the right bank, from which quartz diorite suitable either for concrete aggregate or for rock fill can be obtained. Where it is unweathered, or only slightly weathered, this rock furnishes good material for either use.

Summary

Brief geological examination indicates that the rock at the Hicaco site

affords an excellent foundation and abutments and that the site is suitable for a concrete gravity dam, although considerable residual material overlies the bed rock on the left abutment. Suitable rock for aggregate is available at the dam site.

A comparatively small amount of core drilling will be required to determine the details of the foundation, abutments and rim.

- - -- -o- - - - -

Report of Mr. Robert A. Laurence, Geologist. December 14, 1945

Hicaco Site

The Hicaco site is on Hicaco River, about nine miles southeast of Rio Grande and about 26 miles southeast of San Juan. It is on the Caribbean National Forest. It was examined briefly on December 5, 1945. This site is only a short distance upstream from the original Hicaco site, which the writer visited in 1943, and the regional features mentioned in that report do not need to be repeated here. The present site is located on the same intrusive body of quartz diorite as the original site.

Nine diamond drill holes (1-1/8" diameter cores) were drilled at this site in 1945 by the Authority, and these cores have been examined by the writer. Neither the cores nor the logs of 14 holes drilled by the Forest Service in 1938 are available, although elevations of top of rock as reported from these holes are available. The location was shifted to the present site because of topographic advantages indicated by the detailed surveys. Altitude of the river bed is 2020 feet, and the proposed spillway elevation is 2060 feet.

There is very little rock exposed at the present site, the only outcrops being on the left bank and in the river bed, about 200 feet downstream. Elsewhere, the bed rock is covered by a thick mantle of residual soil and decomposed granite ranging in thickness (as indicated in the drill holes) from about 12 feet near the river to more than 130 feet on the left bank.

The rock exposed in the river, below the site, and in all the drill cores, is a massive, coarse-grained quartz diorite with abundant crystals of hornblende and plagioclase feldspar 4 to 8 mm. in length, and lesser amounts of quartz. It is a fresh, sound rock showing no obvious alteration, other than weathering, and is very hard, as the core drilling clearly demonstrated. In these exposures, the rock is cut by many joints and zones of shearing, which

may be expected to be present beneath the residual covering at the dam site. The principal directions of these are:

N60E, dip 75°SE
N25E, dip 70°NW
N50-60W, vertical
N85W, vertical

(There are also flat joints, probably the result of spheroidal weathering, which would not be present in fresh rock, and are not present in the cores.) Shear zones in the N60E and N85W systems, and especially the intersections of the N25E joints with the N60E shear zones, are the most weathered parts of these exposures, and it is probable that these are also zones of hydrothermal alteration of the original rock. In that case, they may be expected to extend into the fresh rock as steep, soft, seams like those now exposed in the left abutment at Caonillas dam. The bend in the river just below the dam, where it flows approximately S60W, and the steep, narrow, tributary on the left bank 200 feet upstream, are probably the surface expression of more rapid weathering along these shear zones.

The cores obtained from the drill holes confirm the interpretations made from the surface exposures. Practically 100% core recovery was obtained and much of this core is in pieces six inches to four feet in length. Almost all the core is fresh, unaltered and unweathered rock, and it shows almost no variation in texture or mineral content. The only defects observed in these cores were a few steeply dipping joints and shear zones, some of which are slightly weathered or stained a rusty color. The most conspicuous one of these is at the bottom of hole No. 158 (elev. 1976); many others are shown on the profile on drawing No. 3 of the Hicaco Project report. These weathered zones are only a minor defect in the rock and may be treated without difficulty.

No water losses were reported during rock drilling at this site, and the water table is apparently high, under the abutments. Conditions at the top of rock may be expected to resemble those at Caonillas dam and saddle, due to the similarity of the rocks at the two sites.

No additional exploration is considered necessary.